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Phillips Petroleum Company
Research and Development Report 6512-73

EFFECT OF PREVAPORIZED FUEL ON COMBUSTOR PERFORMANCE

Final Report
(19 June 1972 to 19 March 1973)
June 1973

By
H. T. Quigg

Prepared Under Contract N00140-72-C-1528

For

Naval Air Systems Command
Department of the Navy

By

Phillips Petroleum Company
Bartlesville, Oklahoma

PHILLIPS PETROLEUM COMPANY - RESEARCH AND DEVELOPMENT REPORT 6512-73

Final Report
Naval Air Systems Command Contract N00140-72-C-4528

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SUMMARY

An experimental investigation was conducted, using the Phillips 2-inch combustor operated under conditions simulating those in modern aircraft turbine engines, to determine the effects of differences in JP fuels on flame radiance and exhaust emissions. Five kerosene-type fuels, spanning the range in molecular structure (normal paraffins, isoparaffins, cycloparaffins, and aromatics), were used in the investigation. Two programs were conducted to evaluate the effects of fuels and operating variables on flame radiance and exhaust emissions. One program covered a broad range of combustor pressure, inlet air temperature, and inlet air humidity, with two methods for introduction of fuel to the combustor (prevaporized and pressure atomized, but was limited to a single level of heat-input rate. The other program covered a range of heat-input rates, but was limited in range of inlet air temperature and combustor pressure.

Empirical equations were developed for each of the five responses (flame radiance, nitric oxide, nitrogen oxides, carbon monoxide, and smoke), for both programs. The measured values of unburned hydrocarbons in this investigation were either zero or very low and a detailed analysis of the effects of fuels and operating variables on unburned hydrocarbons was not made. Values were calculated for the responses of the estimated equations at the extremes of the ranges of the operating variables used in developing the equations. These data are presented in graphical form to allow visual comparisons of the effects of fuels and operating variables.

Major conclusions drawn from the investigation are (a) where fuel effects are shown an increase in fuel hydrogen content decreases flame radiance, decreases smoke emissions, decreases NO_x and NO emissions slightly and decreases CO emissions, (b) differences in performance, resulting from fuel prevaporization, are variable, usually small, and not always beneficial, (c) an increase in inlet air humidity decreases flame radiance, decreases NO_x and NO emissions, increases CO emissions slightly where humidity has an effect, and has no effect on smoke emissions, (d) an increase in inlet air temperature has a variable effect on flame radiance, decreases smoke, and increases NO_x and NO emissions, (e) an increase in combustor pressure increases flame radiance, increases smoke, and increases NO_x and NO emissions and (f) an increase in heat input rate increases flame radiance, increases smoke, decreases NO_x and NO emissions at a low level of humidity, and decreases CO emissions except at low inlet air temperature with low inlet air humidity.

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PHILLIPS PETROLEUM COMPANY
BARTLESVILLE, OKLAHOMA

Final Report
For
Naval Air Systems Command Contract N00140-72-C-4528

EFFECT OF PREVAPORIZED FUEL ON COMBUSTOR PERFORMANCE

1. INTRODUCTION

During the period from June 19, 1972 to March 19, 1973 an experimental investigation was conducted by Phillips Petroleum Company under Naval Air Systems Command Contract N00140-72-C-4528 to determine the effect which differences in JP fuels and operating variables can have on flame radiance and exhaust emissions of nitrogen oxides, carbon monoxide, unburned hydrocarbons, and soot.

It has been proposed (1, 2) that prevaporized fuel in aircraft turbine engines could provide better mixing of fuel and air than with pressure atomized fuel and result in less emissions in the combustor exhaust. A number of studies have been conducted by Phillips Petroleum Company covering various aspects of radiation from combustion of hydrocarbon fuels (3, 4, 5, 6, 7) and measurements of smoke emissions (7). Experience gained during these studies aided in the design of an experimental investigation of the effect of prevaporized fuel on combustor performance (8) which was conducted under Naval Air Systems Command Contract N00019-71-C-0486.

For the primary program of the previous investigation (8) five fuels were selected to cover the range of chemical composition of JP-5 fuels. Operating conditions selected included four levels of combustor pressure, four levels of inlet air temperature, three levels of inlet air humidity and single levels of heat input rate and reference velocity. The combustor was operated, using prevaporized fuel, with each of five test fuels at all combinations of combustor pressure, inlet air temperature and inlet air humidity. Measurements were made of flame radiance and exhaust emissions of NO, NO_x, CO, CO_2, hydrocarbons and smoke. In Reference 8 it was recommended that the test program be expanded to include the use of pressure atomized fuels to maximize the effect of differences in the physical properties of the fuels and to extend the investigation to include additional levels of heat input rates with both prevaporized and pressure atomized fuels.

Quantities of the same five fuels used in Reference 8 were available and they were used in the current investigation. In Program 1 the same 48 combinations of operating variables were used as in the previous investigation (8). The remainder of the current investigation was conducted with 21 combinations of combustor pressure, inlet air temperature, heat input rate and inlet air humidity. The five fuels were introduced into the combustor using both prevaporization and pressure atomization. By combining the data obtained in the current investigation with that obtained in the previous investigation (8) direct comparisons can be made of the effects of prevaporized and pressure atomized fuels on the various responses measured. The analysis of these data is presented in this report.

2. CONCLUSIONS

An experimental investigation was conducted, using the Phillips 2-inch combustor operated under conditions simulating those in modern aircraft turbine engines, to determine the effects of differences in JP fuels on flame radiance and exhaust emissions of nitrogen oxides, carbon monoxide, unburned hydrocarbons and soot. Kerosene-type fuels spanning the range in molecular structure (normal paraffins, isoparaffins, cycloparaffins, and aromatics) were used in the investigation. Two programs were conducted to provide an evaluation of the effect of fuels and operating variables on flame radiance and exhaust emissions. One program covered a broad range of combustor pressure, inlet air temperature, inlet air humidity and two methods of introduction of fuel to the combustor (prevaporized and pressure atomized) was limited to a single level of heat input for the five fuels. The other program covered a range of heat input rates but was limited in range for inlet air temperatures and combustor pressure. Measured values of unburned hydrocarbons in this investigation were either zero or very low and a detailed analysis of the effects of fuels and operating variables on unburned hydrocarbons was not made.

A statistical analysis of the data was made and on the basis of the statistically significant main effects and interactions empirical equations were developed for the various responses.

The following conclusions may be drawn from the data:

A. Fuel Effects,

a. Where fuel effects are shown, total radiant energy of the flame decreases with an increase in fuel hydrogen content.

b. At high levels of heat input rate and low levels of inlet air temperature, smoke emissions decrease with an increase in fuel hydrogen content. In the other comparisons the level of smoke was below the threshold of visibility.

c. Fuels, over the range of hydrogen contents included in the investigation, decrease NO_x and NO emissions slightly with an increase in fuel hydrogen content.

d. At a high level of heat input and a low inlet air temperature, CO emissions decrease with an increase in fuel hydrogen content. Fuels had no effect on CO emissions at high inlet air temperatures.

B. Comparisons with Prevaporized and Pressure Atomized Fuels,

a. At high heat input rates and high combustor pressure, flame radiance is less with prevaporized fuel than with pressure atomized fuel at high inlet air temperature, and is greater with prevaporized fuel at low temperature. At low levels of heat input flame radiance was less with prevaporized fuel.

b. Smoke optical density is less with prevaporized fuel than with pressure atomized fuel, when the level is above the threshold for visible smoke.

c. Only small differences in NO_x and NO emissions are shown between prevaporized and pressure atomized fuel with prevaporized fuels being the highest.

d. At a high level of heat input and low inlet air temperature, CO emissions are less with prevaporized fuel. At the lower level of heat input, CO emissions are higher with prevaporized fuel.

C. Effect of Inlet Air Humidity,

a. An increase in inlet air humidity decreases flame radiance.

b. A change in inlet air humidity has no statistically significant effect on smoke emissions.

c. An increase in inlet air humidity decreases NO_x and NO emissions.

d. Where inlet air humidity has an effect on CO emissions the effect is to increase emissions with an increase in humidity.

D. Effect of Operating Variables,

a. At a high level of heat input an increase in inlet air temperature increases flame radiance. At a low level of heat input, flame radiance decreases with an increase in inlet air temperature.

b. An increase in combustor pressure increases flame radiance by a small amount.

c. At high combustor pressure an increase in inlet air temperature decreases smoke emissions below the threshold for visible smoke, and the rate of decrease is less with prevaporized fuel than with pressure atomized fuel.

d. An increase in combustor pressure increases smoke emissions, and the rate of increase is less with prevaporized fuel.

e. An increase in inlet air temperature increases NO_x and NO emissions with the rate of increase being greatest at high pressure.

f. An increase in combustor pressure increases NO_x and NO emissions at high temperature, but has only a slight effect at lower inlet air temperature.

g. An increase in heat input rate increases flame radiance, and the rate of increase is greater with prevaporized fuel.

h. An increase in heat input rate over the range of the experiment increases smoke optical density although the level is below the threshold of visible smoke.

i. An increase in heat input rate decreases NO_x and NO emissions at low levels of inlet air humidity, but has little effect at high levels of inlet air humidity.

j. CO emissions decrease with an increase in heat input rate, except at low inlet air temperature with low inlet air humidity.

3. RECOMMENDATIONS

It is recommended that additional data be obtained and a further study of the data on hand be made to develop a relationship that will provide a method for correcting gaseous emissions to a standard humidity level.

4. RESULTS AND DISCUSSION

The objectives of this experimental investigation were to determine the effects which differences in JP fuels and operating variables have on flame radiance and exhaust emissions of nitrogen oxides, carbon monoxide, unburned hydrocarbon, and soot. Additional objectives were to evaluate the effect of method of introduction of fuel into the combustor on flame radiance and exhaust emissions by the use of prevaporization and pressure atomization of the fuels. This also provided an evaluation of the effect of physical properties of fuels on flame radiance and exhaust emissions. Five kerosene-type fuels were selected to span the allowable range in molecular structure: including normal paraffins, isoparaffins, cycloparaffins and aromatics. Inlet air humidity was included as an operating variable in the investigation.

Two programs were included in this investigation:

> Program 1 was an extension of the study conducted in the previous investigation (8) at four levels of combustor pressure, four levels of inlet air temperature, three levels of inlet air humidity and single levels of heat input rate and reference velocity with the current investigation conducted with pressure atomized rather than prevaporized fuels.
>
> The remainder of the investigation (Program 2) consisted of 21 points as shown in Table 5 with both prevaporized and pressure atomized fuels to evaluate the effect of heat input rate as an operating variable on flame radiance and exhaust emissions.

Detailed data obtained during the current investigation are presented in Appendix 2 (Section 8.). The data obtained with prevaporized fuels at the 48 combinations of operating conditions used in Program 1 are presented in Tables 16, 17, and 19 of Reference 8 and have been combined with the data obtained during the current investigation to permit an evaluation of the effect of the method of introduction of fuel into the combustor on flame radiance and exhaust emissions. Analysis of variance techniques were used to examine the data for flame radiance, smoke emissions, NO_x, NO, and CO emissions for various combinations of operating variables. Values for unburned hydrocarbons were either zero or very low for most of the test points and detailed analyses of the data were not made. Analysis of Variance of data for the various responses indicate numerous interactions and point by point comparisons of data for each response would be required for a rigorous statistical analysis. Such an analysis would be very lengthy and tedious. Empirical equations were developed for each response on the basis of statistically significant main effects and interactions. Since fuels interacted with other variables empirical equations were developed for each of the five fuels for each of the responses rather than trying to include the fuels in a single equation.

Two equations were developed for each response with one set of equations based on the data from Program 1 and the other set of equations based on data from the small program to evaluate the effect of heat input rate.

Program 1 consisted of a balanced 4 x 4 x 3 x 2 program with four levels of combustor pressure from 7.5 to 15.0 atmospheres, four levels of inlet air temperature from 400 to 1000 F, three levels of inlet air humidity from 0.002 to 0.042 pounds of water per pound of dry air and two methods of introduction of fuel to the combustor (prevaporized and pressure atomized). The portion of the data with prevaporized fuels was obtained during the previous investigation (8).

Equations for the small program were based on selected data from the current investigation and the previous investigation (8) to provide a balanced program to evaluate the effect of heat input rate on the various responses. The program selected was a 2 x 2 x 2 x 2 x 3 program with two levels of inlet air temperature of 600 and 800 F, two levels of combustor pressure of 10.0 and 12.5 atmospheres, two levels of heat input rate of 150 and 300 Btu per pound of air, two methods of introduction of fuel to the combustor (prevaporized and pressure atomized), and three levels of inlet air humidity of 0.002, 0.022, and 0.042 pounds of water per pound of dry air. Data with a heat input of 300 Btu per pound of air and with prevaporized fuel were obtained from the previous investigation (8).

With the wise range and multiple levels of the variables in Program 1 the equations developed provide better estimates (at fixed heat input) of the values of the responses covered than the equations developed for the small program. While the equations for the small program provide information as to the effect of heat input on flame radiance and exhaust emissions interactions of heat input with other variables complicates some of the relationships.

The estimated equations for the two programs and the five responses are shown in Tables 18 to 27 of Appendix 3 (Section 9.). A primary objective of the investigation was to evaluate the effects of fuels on flame radiance and exhaust emissions over a wide range of operating conditions. Values of the responses for each equation were calculated at the extremes of the ranges of the operating variables used in developing the empirical equations and the data generated are presented graphically in Figures 13 to 61 in Appendix 3 (Section 9.). These figures provide visual comparisons of the effects of fuels and operating variables on flame radiance and exhaust emissions. The information presented on the figures is discussed in detail in Appendix 3 and the data are summarized in the following paragraphs.

4.1. Fuel Effects

In all graphical comparisons of the effects of fuels on flame radiance and exhaust emissions the fuels have been listed in the order of increasing fuel hydrogen content. The range of fuel hydrogen contents covered was from 13.8 per cent for Fuel D to 15.5 per cent for Fuel E.

The magnitude of the calculated values of total radiant energy vary with levels of combustor pressure, inlet air temperature, inlet air humidity, and heat input rate; however, where fuel effects were shown values of total radiant energy decreased with an increase in fuel hydrogen content.

At high levels of heat input and low levels of inlet air temperature smoke emissions decrease with an increase in fuel hydrogen content. At low levels of heat input or high levels of inlet air temperature the level of

smoke emissions was below the threshold of visible smoke (0.200 optical density) and fuels had very little effect on the level of smoke emissions.

Differences in fuels had very little effect on NO_x and NO emissions; however, where small differences are shown emissions are reduced with an increase in fuel hydrogen content.

At the high level of heat input and an inlet air temperature of 400 F CO emissions decreased with an increase in fuel hydrogen content. Fuels have no appreciable effect on CO emissions at higher inlet air temperatures.

4.2. Effect of Method of Fuel Introduction to Combustor

At high heat input rate and high combustor pressure total radiant energy is greater with pressure atomized fuel than with prevaporized fuel at 1000 F and less than with prevaporized fuel at an inlet air temperature of 400 F. This reversal may be due to poor vaporization of the fuel at the high pressure low temperature conditions which may have moved the zone of maximum intensity of radiation down stream away from the area of measurement. At the low level of heat input total radiant energy was greater with pressure atomized fuel than with prevaporized fuel at all combinations of operating conditions evaluated.

At the high level of heat input smoke optical density was greater with pressure atomized fuel than with prevaporized fuel at the high pressure-low temperature combination of operating conditions. Smoke optical density was also higher with pressure atomized fuel at the low temperature-low pressure combination of operating conditions with Fuel D which has the lowest fuel hydrogen content. In the remaining comparisons the smoke optical density was below the threshold of visible smoke.

The effect of differences in the method of fuel introduction on NO_x and NO are minor with pressure atomization of fuel providing a small reduction over the levels of emissions with prevaporized fuels. Under the conditions of this investigation prevaporization of the fuel did not provide the reduction in NO_x emissions predicted.

At high levels of heat input and an inlet air temperature of 400 F CO emissions, with one exception were greater with pressure atomized fuel than with prevaporized fuel. With the lower level of heat input CO emissions were lower with pressure atomized fuel than with prevaporized fuel.

4.3. Effect of Inlet Air Humidity

With one exception, an increase in inlet air humidity from 0.002 to 0.042 pounds of water per pound of dry air decreased total radiant energy.

No statistically significant effect of inlet air humidity on smoke emissions was found with any of the five fuels.

An increase in inlet air humidity from 0.002 to 0.042 pounds of water per pound of dry air decreased NO_x and NO emissions. The decrease in emissions varied with fuels and operating variables with the magnitude of the decrease being from 6 to 9 pounds of NO_x per 1000 pounds of fuel. The range

in humidities is from 10 per cent relative humidity to 100 per cent relative humidity at 100 F. This range in humidities could be encountered with seasonal and geographic changes and span the 75 grains of water per pound of dry air that the Environmental Protection Agency is recommending as a standard humidity. It is apparent that inlet air humidity is an important factor in NO_x emissions; however, additional data are needed to provide a single correction factor for adjusting the level of NO_x emissions to a fixed level.

At the high level of heat input the effect of an increase in inlet air humidity on CO emissions was small and inconsistent although there was a small increase in CO emissions with an increase in humidity in most of the comparisons. In the small program over a narrow range of pressures CO emissions increased with an increase in inlet air humidity and the rate of increase was greater at a heat input rate of 150 than at 300 Btu per pound of air.

4.4. Effect of Operating Variables

Comparisons of the effects of inlet air temperature, combustor pressure, and heat input rate on total radiant energy and exhaust emissions were confined to Fuel A which was a typical production JP-5.

At the high level of heat input an increase in inlet air temperature from 400 to 1000 F increased total radiant energy and the rate of increase was greater with pressure atomized fuel than with prevaporized fuel. At the low level of heat input total radiant energy decreased with an increase in inlet air temperature from 600 to 800 F. An increase in combustor pressure from 7.5 to 15.0 atmospheres increased total radiant energy and the rate of increase was greater with pressure atomized fuel than with prevaporized fuel. An increase in combustor pressure from 10.0 to 12.5 atmospheres in the small program resulted in a small increase in total radiant energy.

In comparisons of smoke optical density at 15.0 atmospheres combustor pressure an increase in inlet air temperature from 400 to 1000 F decreased smoke to below the threshold for visible smoke. The rate of decrease was greater with pressure atomized fuel than with prevaporized fuel. In other comparisons the level of smoke was below the threshold for visible smoke. An increase in combustor pressure from 7.5 to 15.0 atmospheres increased smoke optical density at the low temperature conditions and the rate of increase in smoke was greater with pressure atomized fuel than with prevaporized fuel.

An increase in inlet air temperature increased NO_x and NO emissions with the rates of increase being greater at the higher pressure. Increasing combustor pressure increased NO_x and NO emissions at high temperature but had only a slight effect on emissions at the lower inlet air temperature.

An increase in inlet air temperature decreased CO emissions although the rate of change varied with operating conditions. An increase in combustor pressure at high temperature had only a small effect on CO emissions. At the low temperature conditions CO emissions decreased with an increase in pressure with prevaporized fuel and decreased and then increased with pressure atomized fuel. This may indicate that fuel vaporization and combustion at the low inlet air temperature and high combustor pressure were poor and resulted in incomplete combustion.

An increase in heat input rate from 150 to 300 Btu per pound of air increased total radiant energy. The rate of increase was less with pressure atomized than with prevaporized fuels. An increase in heat input over the range of the experiment increased smoke optical density although the level of smoke was below the threshold for visible smoke. An increase in heat input rate decreased NO_x and NO emissions at low levels of inlet air humidity but had only a small effect at high levels of inlet air humidity. CO emissions were decreased with an increase in heat input except at low inlet air temperature with low inlet air humidity.

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7. APPENDIX 1

(Equipment and Procedures)

7. APPENDIX 1

(Equipment and Procedures)

7.1. Test Facility

Phillips research facility for testing fuels for gas turbine engines, pictured in part in Figure 1, has been described in detail by Fromm (9). Air is supplied by rotary Fuller compressors and filtered by a Selas Vape-Sorber, both of which can be seen in the foreground. This air is preheated just before it enters the 2-inch combustor test-way by a Thermal Research heat exchanger. Fuel and water (when used to control humidity of the combustor air) are supplied by nitrogen pressurization of their respective tanks. A portion of the metering and automatic control equipment can be seen in Figure 2. In experiments with prevaporized fuel, the fuel is heated in a hot-gas heat exchanger just before injection into the 2-inch combustor test-way. Air flow rates up to 2.0 pounds per second, at inlet air pressures up to 15 atmospheres, and inlet air temperatures up to 1400 F are attainable.

7.2. Phillips 2-Inch Combustor

Two configurations of the Phillips 2-inch combustor were used during various phases of this experimental investigation. A scale diagram of the normal 2-inch combustor for use with atomized fuel is shown in Figure 3. Diagrams of the combustor domes used are shown in Figure 4. Dome XIX provides for the introduction of a stream of pressure atomized fuel with a tangential flow of air and Dome X provides for introduction of prevaporized fuel with a tangential flow of air. Design details for the combustors used with pressure atomized and prevaporized fuels are shown in Table 1. Basically, the combustors embody the principal features used in modern aircraft-turbine engines. They are straight-through, can-type combustors with fuel atomized by a single simplex-type nozzle or introduced as a vapor through a tube into the air stream. The combustor liners were fabricated from 2-inch Schedule 40, Inconel pipe, with added internal deflector skirts for film cooling of surfaces exposed to the flame.

The combustors were equipped with sapphire windows aligned with the primary and secondary air inlet holes of the flame tube as shown in Figure 3. This permitted transmission of radiant energy in the infrared spectral region out to five microns to avoid cut-off of significant radiation from flames, as recommended in Reference 5.

The design of the test-way permitted easy access to the combustor, instrumentation, exhaust sample probe, and sapphire windows. The combustor was inspected, cleaned and reconditioned at frequent intervals during the experimental investigation.

Four chromel-alumel thermocouples were mounted on equal area centers at the location indicated in Figure 5, to measure exhaust gas temperature. All thermocouples were housed in ¼-inch diameter Inconel sheaths for protection. The exhaust section was jacketed with water to increase durability for operation with high temperature gases. Figure 5 shows the location of the cascade holder for six metal strips used to simulate a turbine at the combustor outlet and promote thorough mixing of the exhaust gases prior to sampling. The

location of the exhaust gas sample probe is shown in Figure 5.

The Aerospace Recommended Practice (ARP 1256) of the Society of Automotive Engineers (10) recommends the use of a mixing probe with a minimum of twelve sampling points. The exhaust gas sampling probe used in this experimental program conformed to the SAE ARP 1256.

7.3. Flame Radiation Detector

A Leeds and Northrup No. 8890 double-mirror Rayotube was employed together with a Leeds and Northrup Speedomax Type G potentiometric recorder to measure total radiant energy from flames. This Rayotube has a "total radiation" thermocouple-type detector, and was modified by the use of a sapphire window to allow transmission of significant flame radiation out to a wavelength of five microns, as recommended by Schirmer (5).

This Rayotube contained an internal shunt to compensate for its temperature coefficient. In addition, it was protected by the use of an air cooled jacket, which served to minimize error caused by transient changes in test cell temperature and stabilized the Rayotube housing well below its maximum allowable level of 300 F.

The Rayotube was positioned, as indicated in Figure 5, to measure flame radiance from a transverse location across the combustor. It was mounted on a traversing bracket which allowed for positioning by remote control from outside the test cell during operation of the combustor at high pressure and temperature. This made it possible to change the point of observation of the flame from the primary air-inlet holes (Station No. 1) to the secondary air-inlet holes (Station No. 2) in the combustor, without interruption of the test. Movement of the Rayotube position could introduce an alignment error. In a previous study with atomized fuel (6) it was found that with the chosen operating conditions the location of the maximum flame radiance would remain in the primary combustion zone (Station No. 1). In the previous study with prevaporized fuel (8) it was found that over the range of conditions investigated the maximum flame radiance would remain in the secondary combustion zone (Station No. 2). Thus in the current investigation measurements of flame radiance were made at Station No. 1 for tests with pressure atomized fuel and at Station No. 2 for prevaporized fuels.

The apparatus used for the calibration of the Rayotube at temperatures up to 2250 F is shown in Figure 6. The black body target was designed in accordance with Reference 11 to insure a uniform emissivity approaching one. The target was enclosed in a muffle furnace, controlled at the desired temperatures. These were measured by means of a chromel-alumel thermocouple and a Brown potentiometer, and were checked by use of a Leeds and Northrup optical pyrometer. The Rayotube, with the sapphire window in place to simulate that of the combustor, was focused on the black body target, the opening of which simulated that in the flame tube. The generated emf at the controlled temperatures was recorded by the Speedomax for development of the temperature-millivoltage calibration.

For calibration at temperatures from 1900 to 3000 F, a Remmey gas fired furnace with a high alumina (90 per cent) refractory lining was used. The furnace cavity was assumed to be black body. The Rayotube, with the

sapphire window in place, was positioned to view the one cubic foot cavity through a 2-inch diameter port. In this case the temperature of the cavity was measured with a Leeds and Northrup optical pyrometer.

The calibration data for the Rayotube used during this study are given in Table 2 and are plotted in Figure 7. The initial calibration was made during the investigation reported in Reference 6 and a check calibration was made immediately prior to the study under the contract recently completed (8). No significant change in calibration was indicated by the data and the calibration was used in the current study.

The following equation was developed from the initial calibration data in Table 2, relating millivoltage (mv) and temperature (T) in degrees Rankine.

$$\log mv = -14.9906 + 4.5793 \log T$$

This equation is of the expected form (12) and was used in calculating the relationship between recorder scale reading (mv) and total radiant energy (W) from the Stefan-Boltzman Law.

$$W = 1.797 \times 10^{-8} T^4$$

where: W = radiant energy flux per unit area, Btu/ft^2/hr,
T = absolute temperature of source in degrees Kelvin, and
1.797×10^{-8} = Stefan-Boltzman Constant, Btu/ft^2/deg^4/hr.

The resulting calibration curves, made for Speedomax recorder compensator settings of 10 and 30 to increase accuracy in covering the range in total radiant energy of interest, are shown in Figures 8 and 9, respectively. A Speedomax recorder compensator setting of 10 was used when measuring flame radiation intensities in the 15,000 to 150,000 Btu/ft^2/hr range, and increased to 30 for measurement of intensities up to 400,000 Btu/ft^2/hr.

7.4. Measurement of Emissions

7.4.1. Exhaust Smoke Measurement

A Von Brand smokemeter was used in this investigation to measure smoke in the combustor exhaust. This meter, which is pictured in Figure 10, was equipped with a vacuum pump, Whatman No. 4 filter-tape, 2-inch per minute tape drive, and a ½-inch smoke trace aperature in a heated filter head. A portion of exhaust gas was passed through a heated line to a vented 500-ml flask and samples were removed by vacuum through the heated filter-head to the moving filter tape. Samples were obtained with a pressure drop of five inches of mercury across the filter tape.

The relative degree of "blackness" or density of the respective Von Brand filter tapes were measured with a Welch Densichron and an associated Relfection Density Unit. The Densichron was calibrated with a Welch Gray Scale based on MgO = 100% reflectance or 0.000 Optical Density. The meter scale of the Densichron may be read in terms of per cent Reflectance or Optical Density. The Reflectance scale is linear and the Optical Density scale is logarithmic.

On the basis of previous studies (7), smoke evaluations in these studies were recorded in terms of Optical Density.

7.4.2. Exhaust Sample System

A sampling system conforming to Society of Automotive Engineers ARP 1256 (10) was used to obtain samples of exhaust gas from the combustor. This system provided close control of temperature of the exhaust gas sample and provided a minimum of residence time for the gas in the system. As recommended, the system included a twelve-point mixing probe to obtain a representative sample of the gas across the combustor exit. A schematic of the sample system is shown in Figure 11.

7.4.3. Measurement of CO, NO, NO_x, HC and CO_2

The following instruments for continuous monitoring of gaseous emissions from the combustor were used during this investigation.

A. Beckman Model 402, High Temperature, Flame Ionization, Total Hydrocarbon, Continuous Analyzer.
0-10/0-100/0-1,000/0-10,000 ppm Carbon (Propane in Air).

B. Thermo Electron Model 10A, Chemiluminescent, Self-Contained, Continuous Analyzer.
0-10/0-25/0-100/0-250/0-1,000/0-2,500/0-10,000 ppm NO-NO_x.

C. Beckman Model 315BL, Non-Dispersive Infrared, Continuous Analyzer.
0-100/0-200/0-500 and 0-1,000/0-2,000/0-5,000 ppm CO.

D. Beckman Model 315 B, Non-Dispersive Infrared, Continuous Analyzer.
0-6,000/0-30,000/0-150,000 ppm CO_2.

A Texas Instruments Servo/Riter II, 4-channel recorder was used to record the data from these instruments. A view of these instruments is shown in Figure 12.

At each test point the exhaust emissions were monitored for five minutes after stabilization of the combustor. Five minute traces were made of CO, CO_2 and hydrocarbon emission measurements and 2½ minute traces of NO and NO_x emission data were obtained.

7.4.4. Calculation of Emissions

The measurements of pollutant concentration in the exhaust gas from an engine have no real meaning when comparing a gas turbine with other powerplants. Overall, the gas turbine operates with fuel-lean mixtures; thus, the emission levels of pollutants are reduced simply by dilution with air. To provide a uniform basis for comparison of emission levels, the measured concentrations of emissions were transformed to emission rates on the basis of pounds of pollutant per hour or Emission Index based on a weight of fuel burned.

The SAE ARP 1256 (10) provides a guide for sampling, measuring and expressing gaseous emissions from gas turbine combustors. In ARP 1256 it is recommended that measurements of NO as well as NO_x be obtained. Also it is recommended that emission rates on the basis of pounds of pollutant per hour as well as Emission Index based on weight of fuel burned be calculated. The equations in ARP 1256 are based upon concentrations of CO, CO_2 and hydrocarbons in the exhaust gas and upon the hydrogen-carbon ratio of the fuel used. Nitrogen dilution of the exhaust gas sample stream was used to prevent condensation of water in the system. Mass emissions on a pounds per hour basis are pertinent to only the particular engine or combustor from which they were obtained while Emission Index values provide information that can be adjusted for engine or combustor size. Mass emissions have been calculated and are reported but have not been used in comparisons.

7.5. Test Program

A previous investigation (8) was conducted to evaluate the effects of fuel and operating variables on flame radiance and exhaust emissions from a combustor operated with prevaporized fuels to minimize the effect of differences in physical properties of the fuels. The current experimental investigation was designed to include the effect of physical properties of the test fuels on flame radiance and exhaust emissions from a combustor and to include heat input rate as one of the operating variables. The effect of physical properties of the test fuels were minimized and maximized by the use of prevaporized and pressure atomized fuel introduction into the combustor.

Five test fuels, representing a wide range of compositions, were used in the previous program (8). Additional quantities of the fuels were available and were used in the current program to permit consolidation of the data obtained with that obtained in the previous program. Pertinent physical and chemical properties of the fuels are shown in Table 3.

The test facility used in this investigation is described in Section 7.1. of this report and the design details of the Phillips 2-inch Combustors selected for use with prevaporized and pressure atomized fuels are shown in Table 1.

Four levels of combustor pressure, four levels of inlet-air temperature, and three levels of inlet-air humidity were used in Program 1 and the details of the operating conditions are shown in Table 4. These are the same operating conditions used in the previous program (8) with the exception that pressure atomization was used ratner than prevaporization of the fuels. Thus direct comparisons of effects of prevaporized and pressure atomized fuels can be made. The five test fuels were selected at random at a given combination of operating variables and the 48 combinations of operating variables were run in a random order. Inlet-air humidity was adjusted by metering water into a heat excahanger mounted in the inlet-air system between the air heater and the combustor inlet.

A small program was included in the experimental investigation to evaluate the effect of heat input rate as an operating variable on flame radiance and exhaust emissions with both prevaporized and pressure atomized fuels. The experiment was a 2 x 2 x 3 factorial design with two levels of combustor pressure, two levels of inlet air temperature and three levels of

inlet air humidity. Nine additional combinations of operating variables were included to provide a measure of non-linear responses and the entire experiment was conducted with both prevaporized and atomized fuels. Details of the operating conditions for these tests are shown in Table 5. Pertinent physical and chemical properties of the five test fuels are shown in Table 3.

Measurements were made of flame radiation and exhaust emissions of smoke, CO, CO_2, NO, NO_x, and hydrocarbons. Measurements of flame radiation were made at the primary air holes (Station No. 1) for tests with pressure atomized fuels and at the secondary air holes (Station No. 2) for tests with prevaporized fuels. Flame radiance measurements were made using equipment described in Section 7.3. Determinations of exhaust smoke were made with the Von Brand smoke meter as described in Section 7.4.1. The exhaust samples for determinations of gaseous emissions (CO, CO_2, NO, NO_x, and hydrocarbons) were diluted with about two parts of heated nitrogen, as shown in Figure 11, to eliminate condensation of water in the test instruments. The instruments and techniques for measuring gaseous emissions are described in Section 7.4.3.

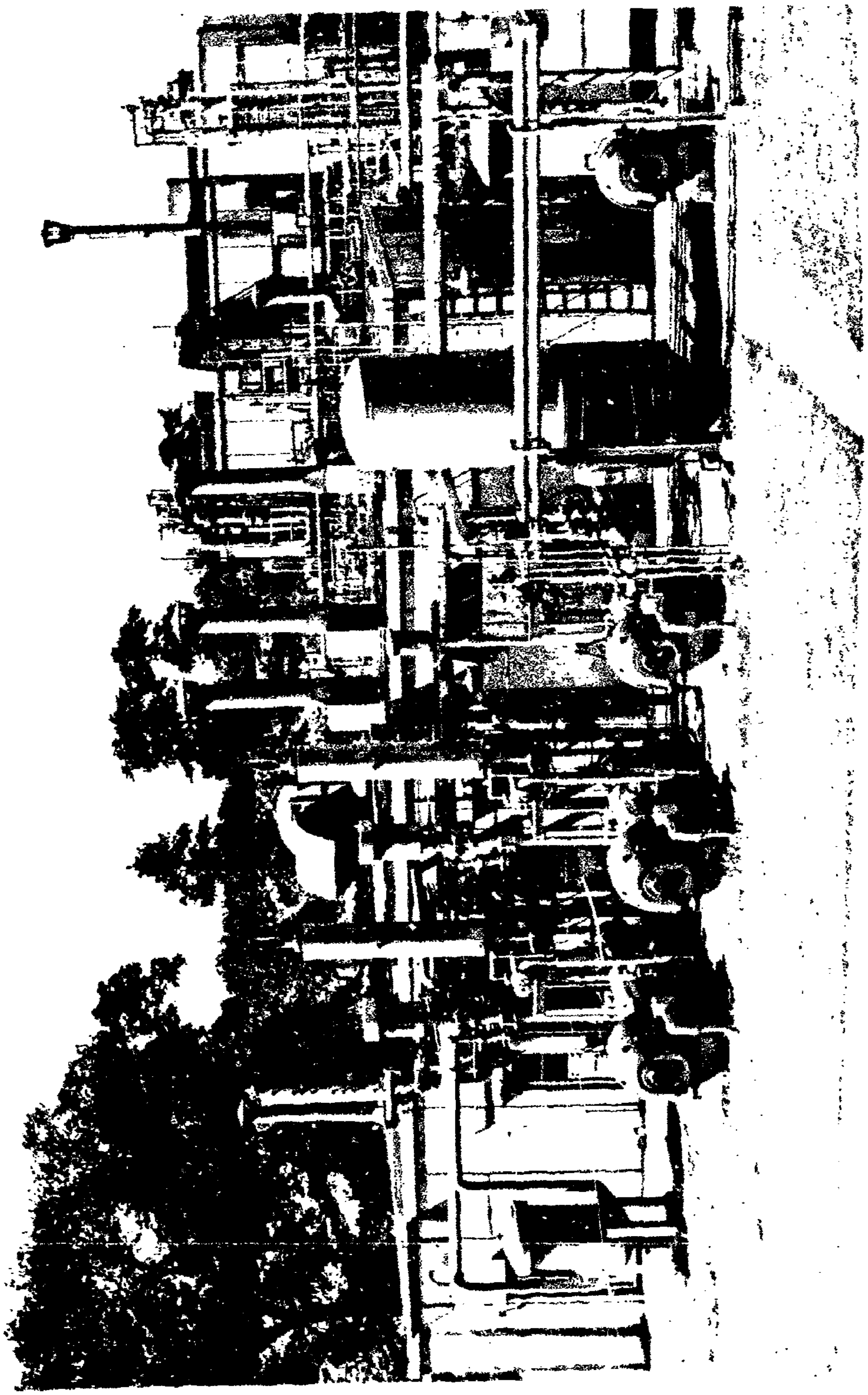

FIGURE 1
PHILLIPS RESEARCH FACILITY FOR JP FUELS

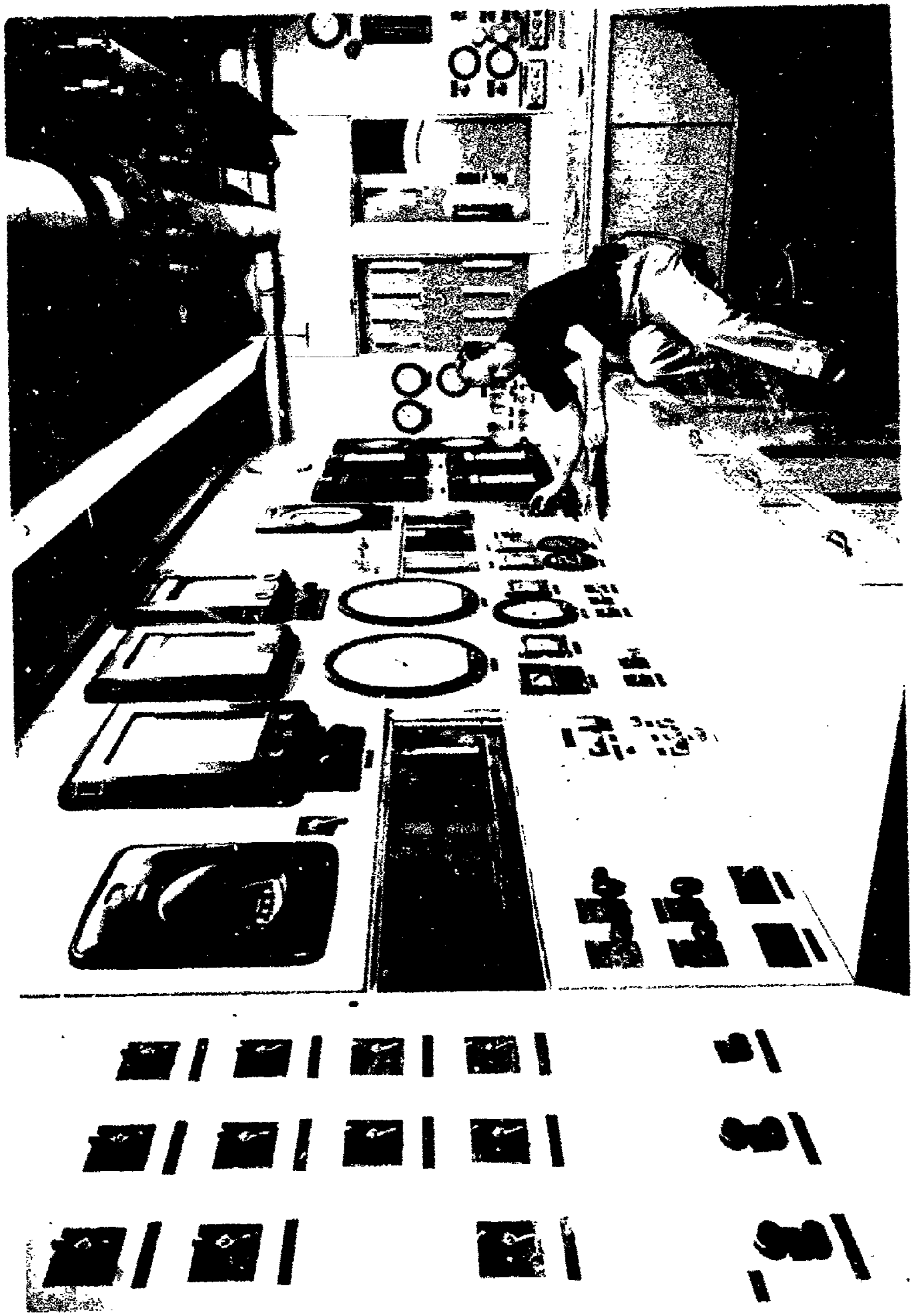

FIGURE 2
CONTROL ROOM FOR HIGH-PRESSURE COMBUSTOR

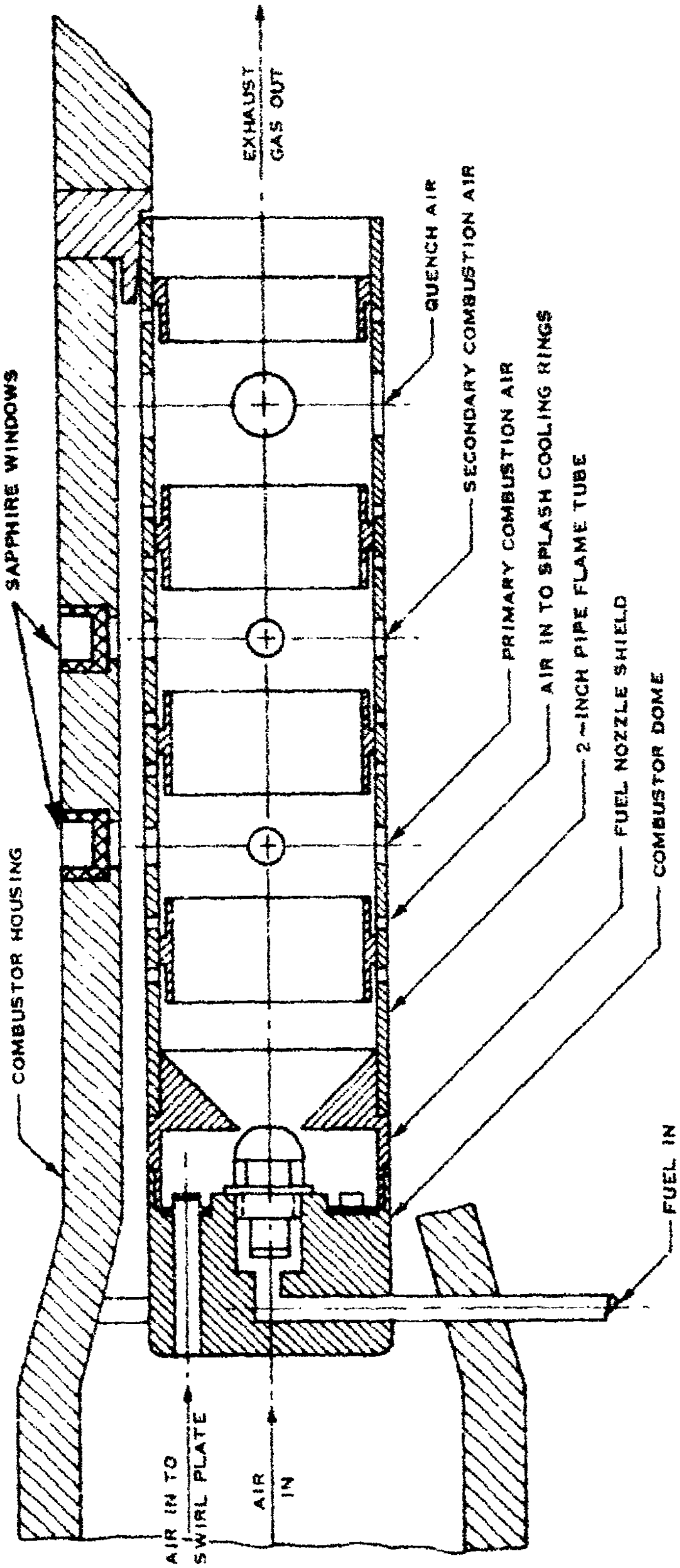

FIGURE 3
PHILLIPS 2 – INCH COMBUSTOR

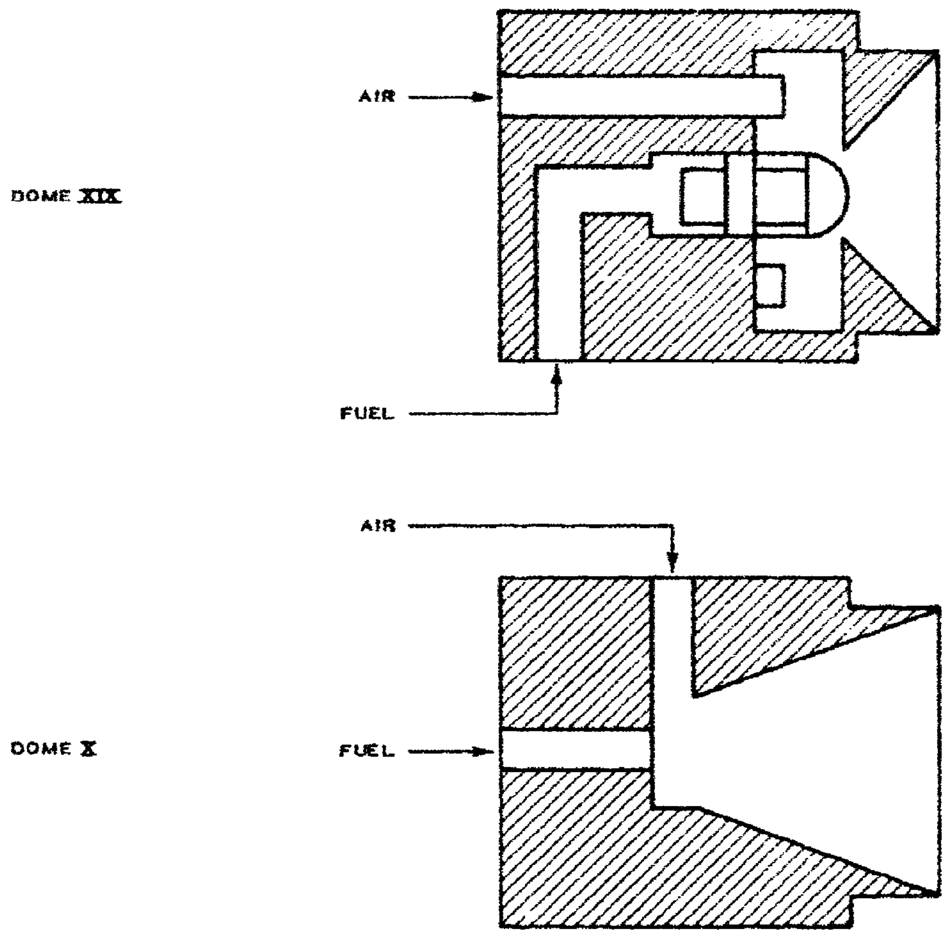

FIGURE 4
PHILLIPS 2-INCH COMBUSTOR DOMES

TABLE 1

DESIGN DETAILS OF PHILLIPS 2-INCH COMBUSTOR FOR STUDY OF FLAME RADIATION

Variable	Combustor Number 45	Combustor Number 71
Dome Configuration	X	XIX
Air Inlet Diameter, in.	0.875	0.781
Inlet Type	Tangent	Tangent
Hole Diameter, in.	0.250	0.250
Number of Holes	6	6
Total Hole Area, sq. in.	0.295	0.295
% Total Combustor Hole Area	7.808	7.808
Fuel Tube Diameter, in.	0.250	...
Penetration, in.	0.000	...
Exit Type	Open	...
Fuel Nozzle		
Type	...	Simplex
Spray Pattern	...	Semi-Solid Cone
Spray Angle, degrees	...	45
Flame Tube Configuration	V	V
1st Station		
Hole Diameter, in.	0.375	0.375
Total Number of Holes	4	4
Total Hole Area, sq. in.	0.442	0.442
% Total Combustor Hole Area	11.699	11.699
2nd Station		
Hole Diameter, in.	0.375	0.375
Total Number of Holes	4	4
Total Hole Area, sq. in.	0.442	0.442
% Total Combustor Hole Area	11.699	11.699
3rd Station		
Hole Diameter, in.	0.625	0.625
Total Number of Holes	4	4
Total Hole Area, sq. in.	1.224	1.224
% Total Combustor Hole Area	32.398	32.398
Wall Cooling Air		
Hole Diameter, in.	0.125	0.125
Holes/Station	16	16
Number of Stations	7	7
Total Number of Holes	112	112
Total Hole Area, sq. in.	1.375	1.375
% Total Combustor Hole Area	36.394	36.394
Total Combustor Hole Area, sq. in.	3.778	3.778
% Cross Sectional Area	142.1	142.1

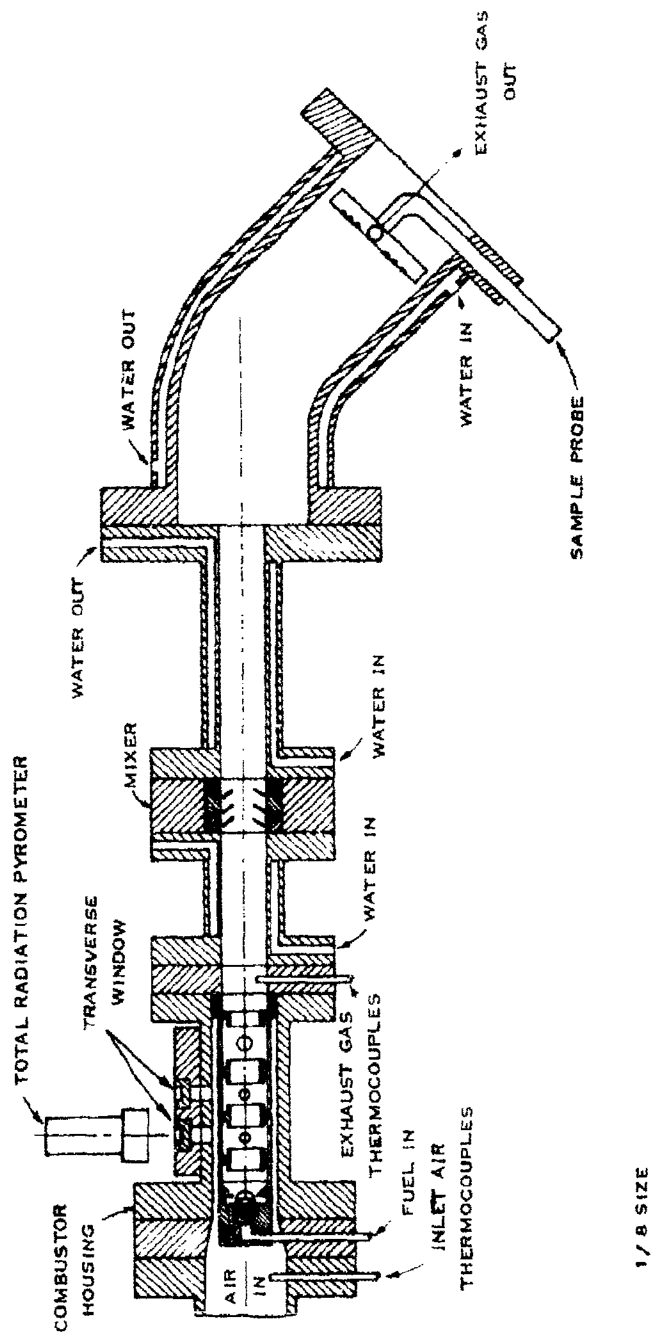

FIGURE 5
SCHEMATIC OF TEST-WAY FOR STUDY OF EXHAUST EMISSIONS
FROM CONTINUOUS COMBUSTION PROCESSES

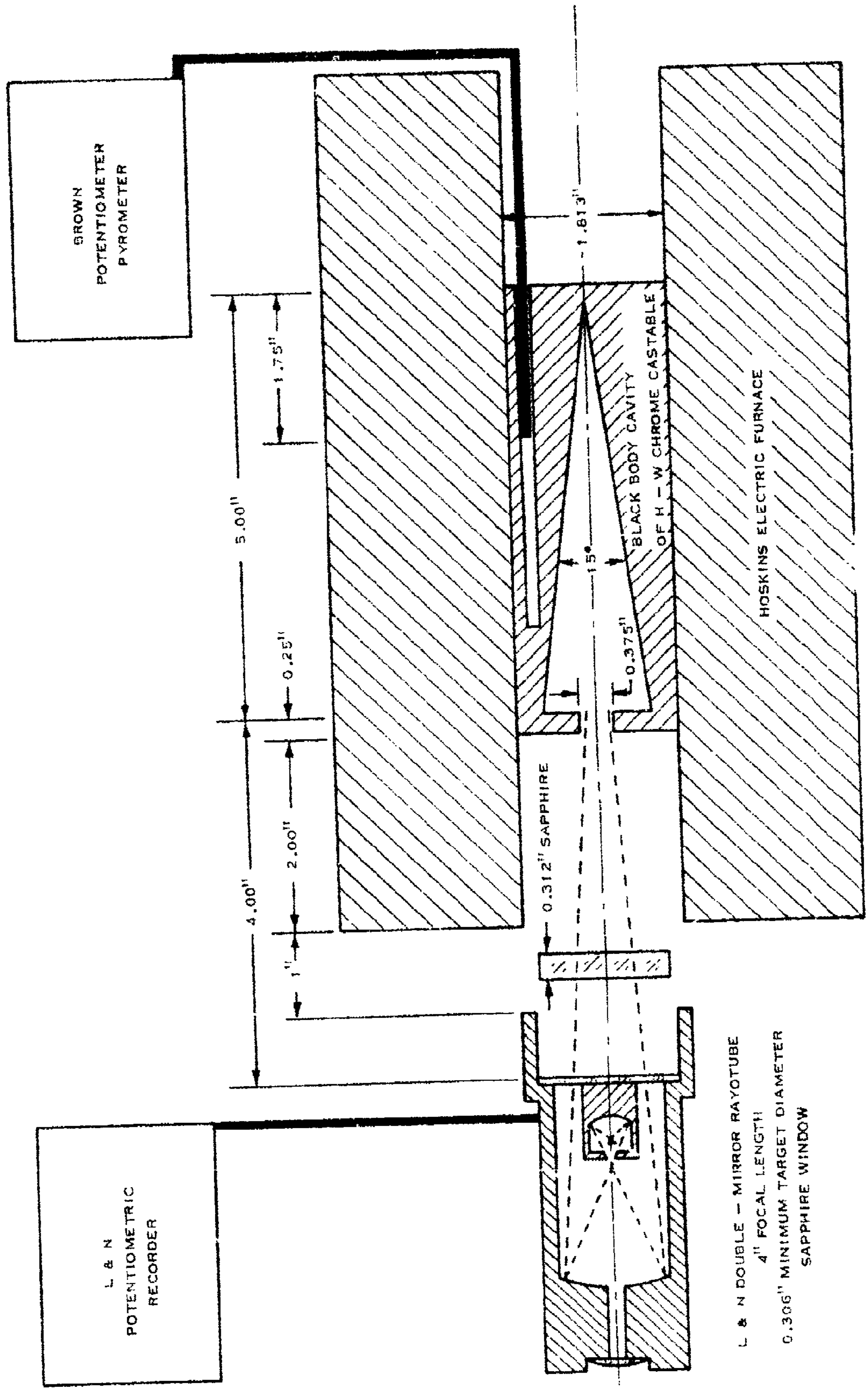

FIGURE 6
APPARATUS FOR CALIBRATION OF
TOTAL RADIATION PYROMETER

TABLE 2

CALIBRATION DATA FOR TOTAL RADIATION PYROMETER

Temperature, F	Initial Calibration, millivolts	Check Calibration, millivolts
1230	...	0.57
1300	...	0.67
1395	...	0.93
1405	0.91	...
1485	...	1.16
1600	...	1.53
1669	1.82	...
1695	...	1.84
1810	...	2.33
1817	2.40	...
1900	2.96 (a)	...
1925	...	2.90
2000	...	3.37
2020	...	3.48
2025	3.55	...
2055	3.98 (a)	...
2100	...	4.09
2200	...	4.83
2245	5.42	...
2720	11.76 (a)	...
2800	13.00 (b)	...
2989	15.71 (a)	...

Notes:

(a) Points taken in Remmey Furnace

(b) Leeds and Northrup factory calibration point

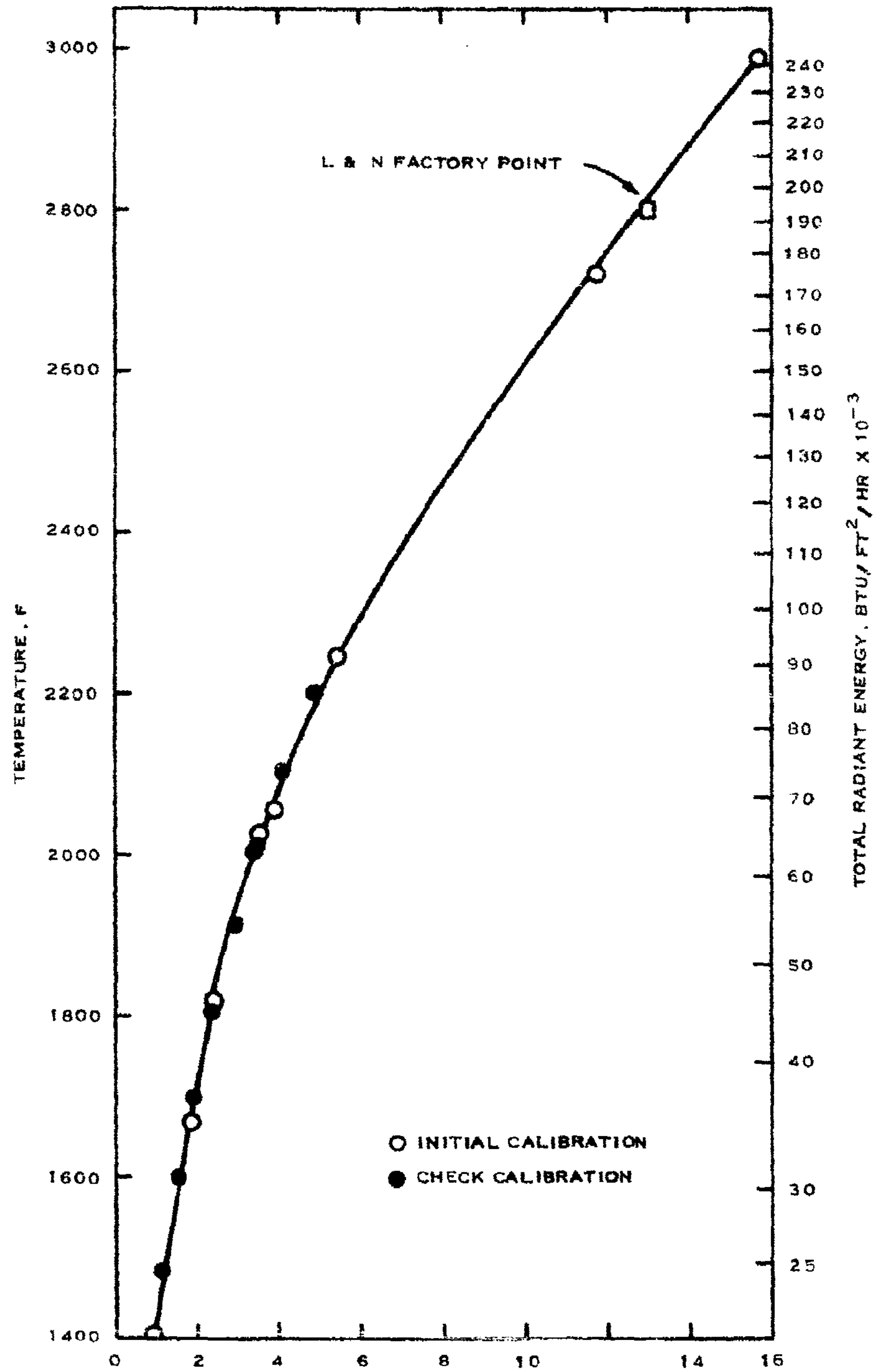

FIGURE 7
CALIBRATION OF TOTAL RADIATION PYROMETER
(TEMPERATURE VS MILLIVOLTS)

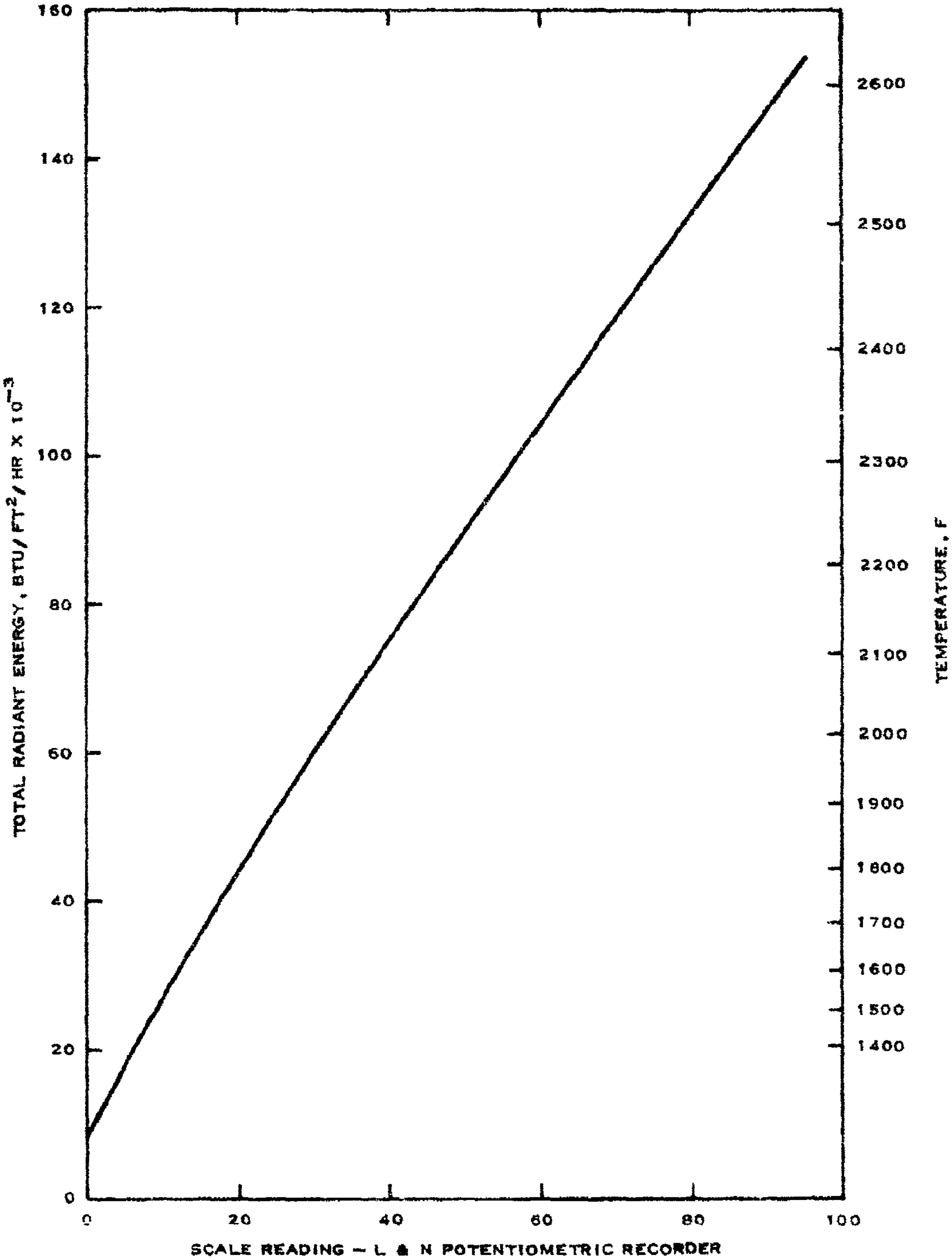

FIGURE 8
CALIBRATION OF TOTAL RADIATION PYROMETER
(RADIATION VS MILLIVOLTS)
(COMPENSATOR SETTING = 10)

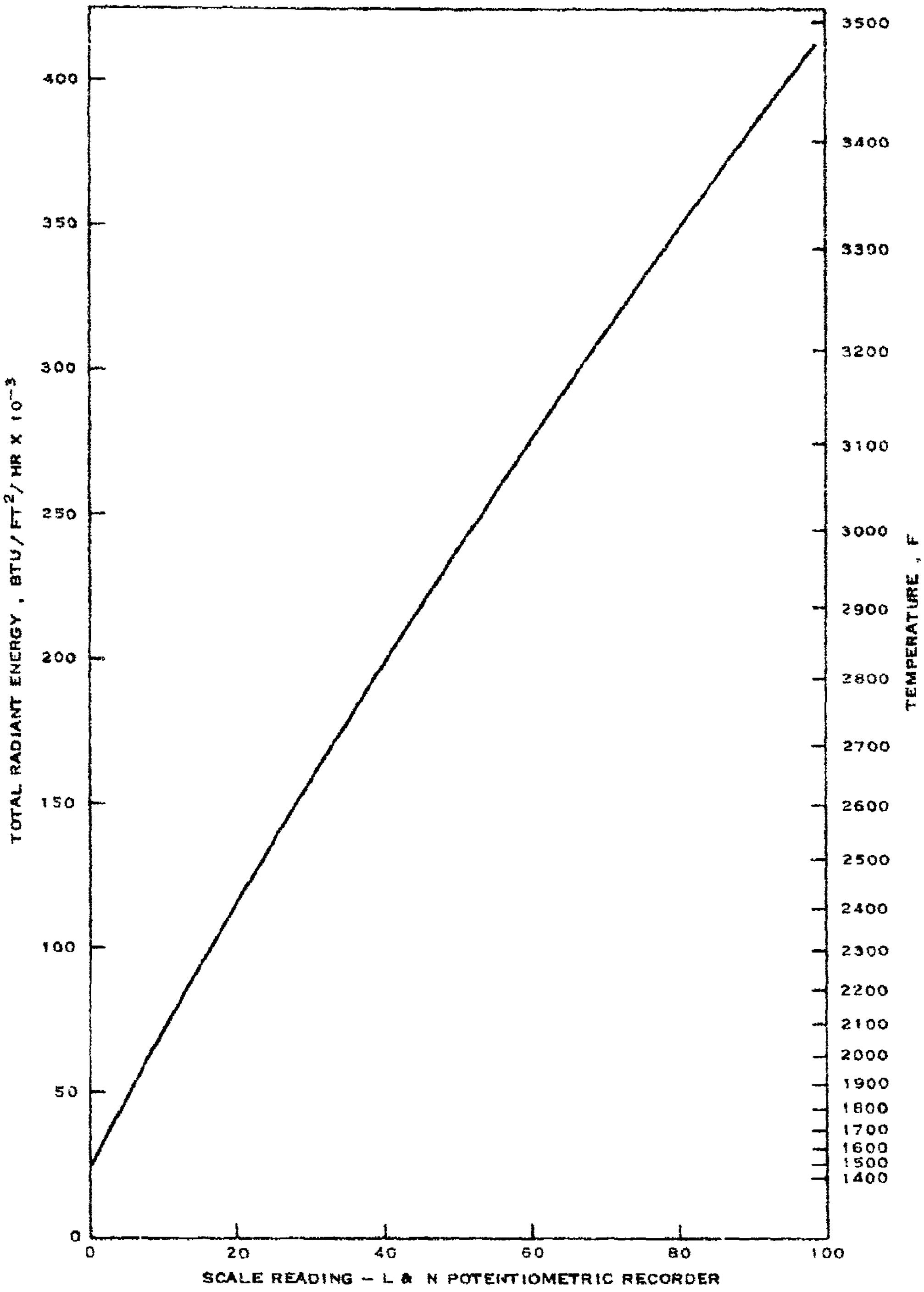

FIGURE 9
CALIBRATION OF TOTAL RADIATION PYROMETER
(RADITATION VS MILLVOLTS)
(COMPENSATOR SETTING=30)

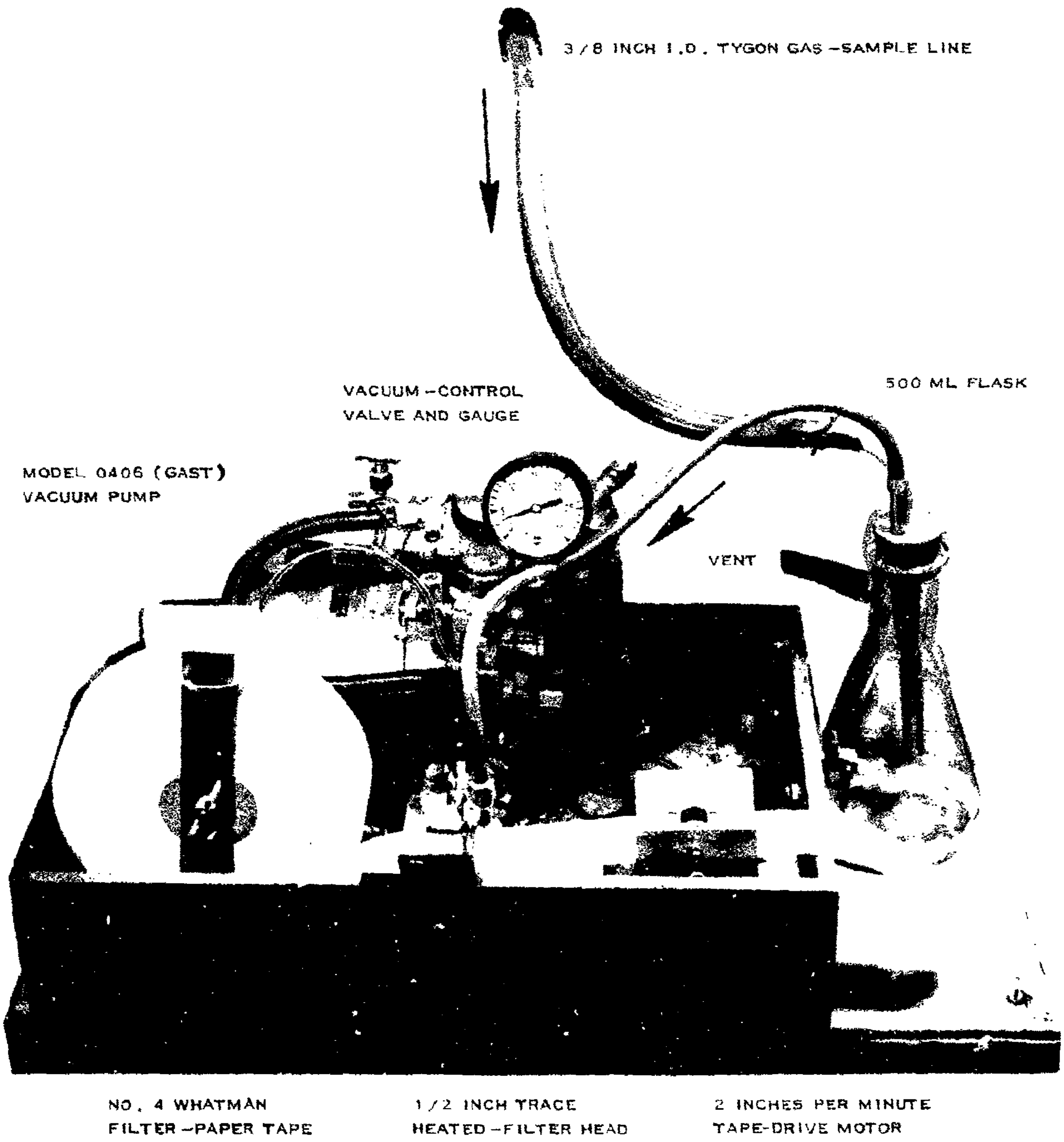

FIGURE 10
VON BRAND SMOKEMETER

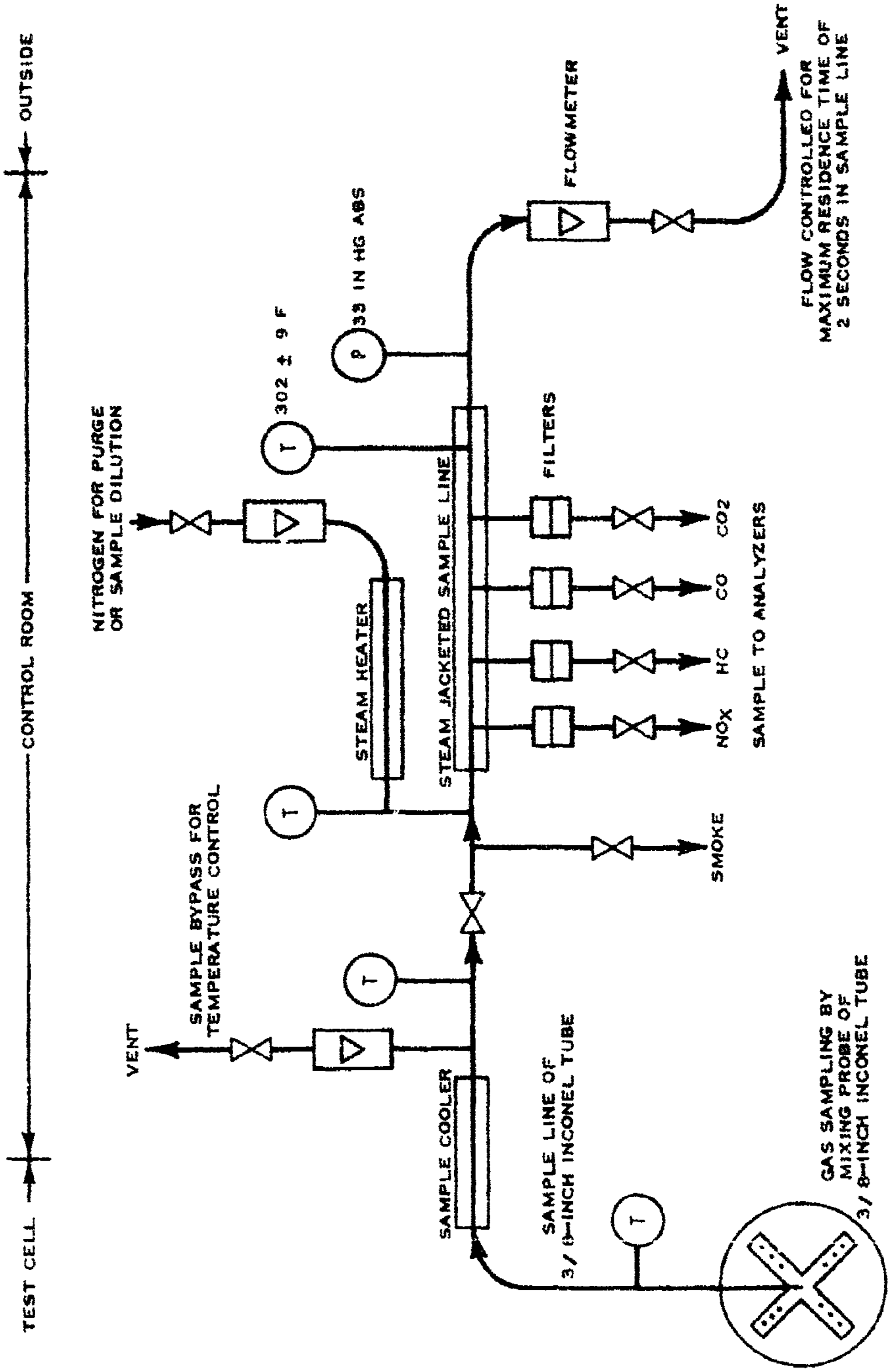

FIGURE 11
SCHEMATIC DIAGRAM OF SAMPLING SYSTEM

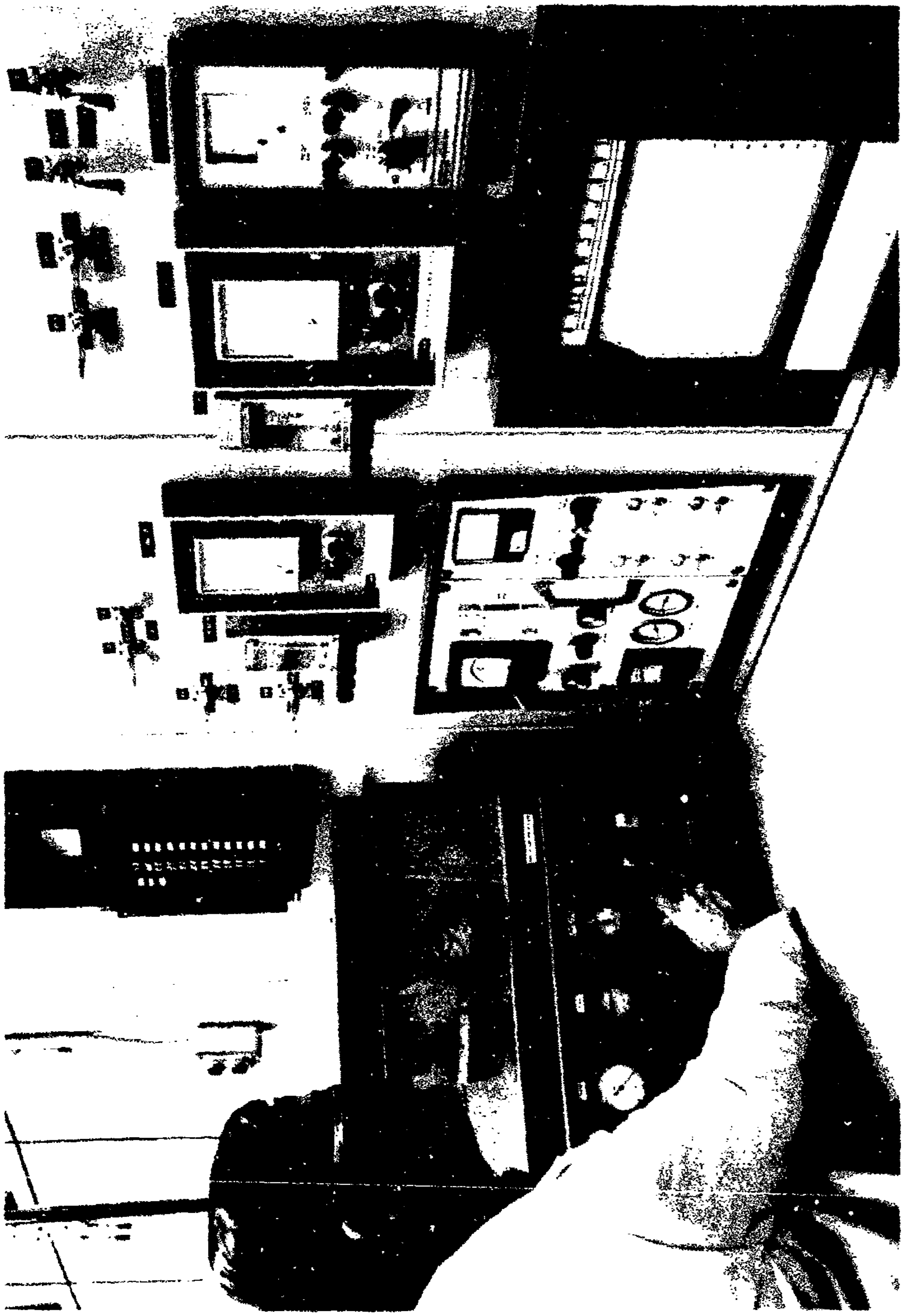

FIGURE 12
INSTRUMENTATION FOR CONTINUOUS MONITORING OF EMISSIONS

TABLE 3

PHYSICAL AND CHEMICAL PROPERTIES OF TEST FUELS
(Primary Program)

	A Typical Production JP-5	B Isoparaffin JP-5	C Cyclo-Paraffin JP-5 (RP-1)	D JP-5 Referee	E n-Paraffin JP-5 (JP-150)
Identification Number	BJ67-9-G7	BJ67-9-A5	BJ67-9-G12	BJ67-9-G4	BJ71-8-A1
ASTM Distillation, F					
Initial Boiling Point	340	363	338	350	410
5 vol % evaporated	359	371	378	370	421
10 vol % evaporated	362	373	392	376	421
20 vol % evaporated	371	377	404	387	422
30 vol % evaporated	376	380	418	397	423
40 vol % evaporated	387	383	427	409	423
50 vol % evaporated	398	389	437	420	423
60 vol % evaporated	409	396	448	432	423
70 vol % evaporated	424	406	460	445	424
80 vol % evaporated	442	422	474	458	426
90 vol % evaporated	461	456	492	476	430
95 vol % evaporated	474	491	506	492	442
End Point	496	507	526	516	478
Residue, vol %	0.8	1.4	1.0	1.2	0.5
Loss, vol %	0.0	0.2	0.0	0.0	0.0
Gravity, degrees API	46.6	53.4	42.9	42.1	56.1
Density, lbs/gal	6.615	6.371	6.756	6.786	6.280
Heat of Combustion, net, Btu/lb	18,670	18,875	18,720	18,430	18,967
Hydrogen Content, wt %	14.2	15.0	14.3	13.8	15.5
Smoke Point, mm	27.2	40.4	28.7	19.7	42.0
Sulfur, wt %	0.0012	0.0003	0.0235	0.37	0.04
Gum, mg/100 ml	0.0	0.8	0.5	1.1	0.9
Composition, vol %					
Normal Paraffins	52.8	...	39.8	50.1	98.45
Iso-Paraffins		92.2			1.55
Cyclo-Paraffins	34.5	6.2	56.6	25.7	0.0
Olefins	0.1	1.0	0.2	2.7	0.0
Aromatics	12.6	0.6	3.4	21.5	0.0

TABLE 4

PHILLIPS 2-INCH COMBUSTOR OPERATING CONDITIONS FOR THE STUDY OF EMISSIONS (a)
(Program 1)

Test Cond. No.	Combustor Pressure, atm	Inlet Air Temp., F	Inlet Air Flow, lb/sec	Inlet Water Flow, lb/hr	Fuel Flow, lbs/hr A BJ-67 -9-G7	B BJ-67 -9-A5	C BJ-67 -9-D12	D BJ-67 -9-G4	E BJ-71 -8-A1
1	7.5	400	0.892	...	51.6	51.0	51.5	52.3	48.2
2	7.5	400	0.864	62.2	50.0	49.4	49.8	50.6	46.7
3	7.5	400	0.838	120.7	48.5	48.0	48.3	49.1	45.3
4	7.5	600	0.724	...	41.9	41.4	41.8	42.4	39.2
5	7.5	600	0.701	50.5	40.6	40.1	40.4	41.1	37.9
6	7.5	600	0.680	97.9	39.3	38.9	39.2	39.8	36.8
7	7.5	800	0.609	...	35.2	34.8	35.1	35.7	32.9
8	7.5	800	0.590	42.5	34.1	33.8	34.0	34.6	31.9
9	7.5	800	0.572	82.4	33.1	32.7	33.0	33.5	30.9
10	7.5	1000	0.525	...	30.4	30.0	30.3	30.8	28.4
11	7.5	1000	0.509	36.6	29.4	29.1	29.4	29.8	27.5
12	7.5	1000	0.493	71.0	28.5	28.2	28.4	28.9	26.7
13	10.0	400	1.19	...	68.8	68.1	68.6	69.7	64.4
14	10.0	400	1.15	82.8	66.5	65.8	66.3	67.4	62.2
15	10.0	400	1.12	161.3	64.8	64.1	64.6	65.6	60.6
16	10.0	600	0.965	...	55.8	55.2	55.7	56.6	52.2
17	10.0	600	0.935	67.3	54.1	53.5	53.9	54.8	50.6
18	10.0	600	0.907	130.6	52.5	51.9	52.3	53.2	49.1
19	10.0	800	0.812	...	47.0	46.5	46.8	47.6	43.9
20	10.0	800	0.787	56.7	45.5	45.0	45.4	46.1	42.6
21	10.0	800	0.763	109.0	44.1	43.7	44.0	44.7	41.3
22	10.0	1000	0.701	...	40.6	40.1	40.4	41.1	37.9
23	10.0	1000	0.679	48.9	39.3	38.8	39.2	39.8	36.7
24	10.0	1000	0.658	94.8	38.1	37.6	38.0	38.6	35.6

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.

TABLE 4 (Continued)

PHILLIPS 2-INCH COMBUSTOR OPERATING CONDITIONS FOR THE STUDY OF EMISSIONS (a)
(Program 1)

Test Cond. No.	Combustor Pressure, atm	Inlet Air Temp., F	Inlet Air Flow, lb/sec	Inlet Water Flow, lb/hr	Fuel Flow, lbs/hr A BJ-67 -9-G7	B BJ-67 -9-A5	C BJ-67 -9-G12	D BJ-67 -9-G4	E BJ-71 -9-A1
25	12.5	400	1.49	...	86.2	85.2	86.0	87.3	80.6
26	12.5	400	1.44	103.7	83.3	82.4	83.1	84.4	77.9
27	12.5	400	1.40	201.6	81.0	80.1	80.8	82.0	75.7
28	12.5	600	1.21	...	70.0	69.2	69.8	70.9	65.4
29	12.5	600	1.17	84.2	67.7	66.9	67.5	68.6	63.3
30	12.5	600	1.11	159.8	64.2	63.5	64.0	65.0	60.0
31	12.5	800	1.02	...	59.0	58.4	58.8	59.8	55.2
32	12.5	800	0.984	70.8	56.9	56.3	56.8	57.7	53.2
33	12.5	800	0.954	137.4	55.2	54.6	55.0	55.9	51.6
34	12.5	1000	0.876	...	50.7	50.1	50.5	51.3	47.4
35	12.5	1000	0.849	61.1	49.1	48.6	49.0	49.8	45.9
36	12.5	1000	0.823	118.5	47.6	47.1	47.5	48.2	44.5
37	15.0	400	1.78	...	103.0	101.8	102.7	104.3	96.3
38	15.0	400	1.73	124.6	100.1	99.0	99.8	101.4	93.6
39	15.0	400	1.68	241.9	97.2	96.1	96.9	98.4	90.9
40	15.0	600	1.45	...	83.9	83.0	83.6	85.0	78.4
41	15.0	600	1.40	100.8	81.0	80.1	80.8	82.0	75.7
42	15.0	600	1.36	195.8	78.7	77.8	78.5	79.7	73.6
43	15.0	800	1.22	...	70.6	69.8	70.4	71.5	66.0
44	15.0	800	1.18	85.0	68.3	67.5	68.1	69.2	63.8
45	15.0	800	1.14	164.2	65.9	65.2	65.8	66.8	61.7
46	15.0	1000	1.05	...	60.7	60.1	60.6	61.5	56.8
47	15.0	1000	1.02	73.4	59.0	58.4	58.8	59.8	55.2
48	15.0	1000	0.988	142.3	57.2	56.5	57.0	57.9	53.4

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.

TABLE 5

PHILLIPS 2-INCH COMBUSTOR OPERATING CONDITIONS FOR THE STUDY OF EMISSIONS (a)
(Prevaporized and Pressure Atomized Fuels)
(Program 2)

Test Cond. No.	Test Conditions	Inlet Air Flow, lbs/sec	Inlet Water Flow, lbs/hr	Fuel Flow, lbs/hr: A BJ-67 -9-G7	B BJ-67 -9-A5	C BJ-67 -9-G12	D BJ-67 -9-G4	E BJ-71 -8-A1
49	$P_1\ T_1\ F_1\ H_0$	0.965	...	27.9	27.6	27.8	28.3	27.5
53	$P_1\ T_1\ F_1\ H_1$	0.935	67.3	27.0	26.8	27.0	27.4	26.6
57	$P_1\ T_1\ F_1\ H_2$	0.907	130.6	26.2	26.0	26.2	26.6	27.8
50	$P_1\ T_2\ F_1\ H_0$	0.812	...	23.5	23.2	23.4	23.8	23.1
54	$P_1\ T_2\ F_1\ H_1$	0.787	56.7	22.8	22.5	22.7	23.1	22.4
58	$P_1\ T_2\ F_1\ H_2$	0.763	109.0	22.2	21.8	22.0	22.4	21.7
51	$P_2\ T_1\ F_1\ H_0$	1.21	...	35.0	34.6	34.9	35.4	34.4
55	$P_2\ T_1\ F_1\ H_1$	1.17	84.2	33.8	33.5	33.8	34.3	33.3
59	$P_2\ T_1\ F_1\ H_2$	1.13	162.7	32.7	32.3	32.6	33.1	32.2
52	$P_2\ T_2\ F_1\ H_0$	1.02	...	29.5	29.2	29.4	29.9	29.0
56	$P_2\ T_2\ F_1\ H_1$	0.984	70.8	28.5	28.2	28.4	28.8	28.0
60	$P_2\ T_2\ F_1\ H_2$	0.954	137.4	27.6	27.3	27.5	28.0	27.2
61	$P_4\ T_4\ F_2\ H_1$	0.962	69.3	41.7	41.3	41.6	42.3	41.1
66	$P_0\ T_4\ F_2\ H_1$	0.641	46.2	27.8	27.5	27.7	28.2	27.4
67	$P_3\ T_4\ F_2\ H_1$	1.28	92.2	55.5	54.9	55.4	56.3	54.7
68	$P_4\ T_0\ F_2\ H_1$	1.30	93.6	56.4	55.8	56.2	57.1	55.5
69	$P_4\ T_3\ F_2\ H_1$	0.764	55.0	33.1	32.8	33.1	33.6	32.6
64	$P_4\ T_4\ F_2\ H_0$	0.992	...	43.0	42.6	42.9	43.6	42.4
65	$P_4\ T_4\ F_2\ H_2$	0.933	134.4	40.5	40.0	4004	41.0	39.8
63	$P_4\ T_4\ F_0\ H_1$	0.962	69.3	18.6	18.3	18.5	18.8	18.3
62	$P_4\ T_4\ F_3\ H_1$	0.962	69.3	64.9	64.2	64.8	65.8	63.9

(a) Reference Velocity = 140 ft/sec.
Combustor Pres., P_0 = 7.5, P_1 = 10.0, P_2 = 12.5, P_3 = 15.0, P_4 = 11.25 atm.

Inlet Air Temp., T_0 = 400F, T_1 = 600F, T_2 = 800F, T_3 = 1000F, T_4 = 700F.

Heat Input, F_0 = 100, F_1 = 150, F_2 = 225, F_3 = 350 Btu/lb air.

Inlet Air Humidity, H_0 = 0.2, H_1 = 2.2, H_2 = 4.2 lbs H_2O/lb dry air x 100.

Inlet Temperature of Prevaporized Fuel = 700F.
Combustor Configuration No. 45 for Prevaporized Fuel.
Combustor Configuration No. 71 for Pressure Atomized Fuel.

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8. APPENDIX 2

(Experimental Results)

8. APPENDIX 2

(Experimental Results)

8.1. Flame Radiation

Rayotube readings obtained at each test point during the investigation were converted to total radiant energy values using the calibration curves shown in Section 7. and the values are presented in Tables 6, 7, and 8. The data presented in Tables 6 and 8 were obtained with pressure atomized fuels and the Rayotube readings were obtained at Station No. 1 of the flame tube. The Rayotube readings with prevaporized fuels are shown in Table 7 and the readings were obtained at Station No. 2 of the flame tube.

8.2. Exhaust Smoke Measurements

Smoke optical density measurements were obtained with each fuel-operating variable combination as indicated in Section 7. and the data are presented in Tables 9, 10, and 11.

8.3. Gaseous Emissions

The concentrations of CO_2, CO, NO, NO_x, and hydrocarbons in the diluted exhaust gas at each combination of fuels and operating variables were measured using the continuous monitoring instruments described in Section 7. and the data are shown in Tables 12, 13, and 14. The mass of emissions in lb/hr and the Emission Index in lbs/1000-lbs of fuel were calculated for each test point as described in Section 7. and the data are shown in Tables 15, 16, and 17.

TABLE 6

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON FLAME RADIATION (a)
(Program 1)

Test Cond. No.	Combustor Pressure, atm	Inlet Air Temp., F	Inlet Air Humidity, % (b)	Flame Radiation With Fuels (c) A BJ-67-9-G7	B BJ-67-9-A5	C BJ-67-9-G12	D BJ-67-9-G4	E BJ-71-8-A1
1	7.5	400	0.2	78.8	46.3	56.6	82.8	37.7
2	7.5	400	2.2	67.1	42.3	61.8	87.6	34.9
3	7.5	400	4.2	61.3	34.0	54.0	76.7	27.0
4	7.5	600	0.2	107.2	83.4	103.7	110.6	59.2
5	7.5	600	2.2	95.2	62.5	90.1	39.7	55.4
6	7.5	600	4.2	87.8	58.1	79.3	87.8	45.9
7	7.5	800	0.2	137.8	109.2	133.3	164.2	89.2
8	7.5	800	2.2	128.7	97.3	124.0	150.2	79.2
9	7.5	800	4.2	102.6	67.8	96.6	125.3	57.0
10	7.5	1000	0.2	170.7	132.4	163.3	174.2	116.5
11	7.5	1000	2.2	152.1	115.3	145.9	175.0	100.6
12	7.5	1000	4.2	138.1	106.3	130.5	162.0	88.4
13	10.0	400	0.2	66.6	38.5	59.5	95.8	39.9
14	10.0	400	2.2	47.5	29.5	45.7	58.7	32.8
15	10.0	400	4.2	37.0	24.8	36.7	46.3	27.4
16	10.0	600	0.2	119.7	91.7	100.3	130.6	61.0
17	10.0	600	2.2	112.6	77.4	95.4	104.8	61.5
18	10.0	600	4.2	97.5	67.7	91.9	118.0	54.1
19	10.0	800	0.2	157.9	126.2	147.3	171.8	121.1
20	10.0	800	2.2	137.7	111.4	131.0	149.7	97.1
21	10.0	800	4.2	125.6	99.0	116.5	143.2	85.9
22	10.0	1000	0.2	202.6	172.9	192.3	194.3	156.5
23	10.0	1000	2.2	182.3	149.9	177.6	197.4	135.6
24	10.0	1000	4.2	169.0	133.4	162.0	181.9	119.9

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.

(b) Lbs H_2O/lb dry air x 100.

(c) Total Radiation Pyrometer (Rayotube), Btu/ft^2/hr x 10^{-3}.

TABLE 6 (Continued)

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON FLAME RADIATION (a)
(Program 1)

Test Cond. No.	Combustor Pressure, atm	Inlet Air Temp., F	Inlet Air Humidity, % (b)	Flame Radiation With Fuels (c) A BJ-67 -9-G7	B BJ-67 -9-A5	C BJ-67 -9-G12	D BJ-67 -9-G4	E BJ-71 -8-A1
25	12.5	400	0.2	123.5	50.4	78.0	99.6	54.3
26	12.5	400	2.2	69.1	37.8	62.2	83.6	45.3
27	12.5	400	4.2	49.8	31.0	51.1	63.4	34.1
28	12.5	600	0.2	143.9	95.3	149.5	161.7	115.2
29	12.5	600	2.2	122.7	65.6	101.1	138.4	76.2
30	12.5	600	4.2	79.3	45.3	78.0	100.7	56.9
31	12.5	800	0.2	186.0	166.0	177.8	194.9	155.6
32	12.5	800	2.2	168.9	140.4	164.8	179.2	131.9
33	12.5	800	4.2	151.8	127.9	148.8	167.8	116.7
34	12.5	1000	0.2	216.9	186.9	221.6	231.1	185.2
35	12.5	1000	2.2	194.0	168.9	183.3	199.0	163.6
36	12.5	1000	4.2	183.2	144.2	174.2	198.3	141.7
37	15.0	400	0.2	143.0	107.7	144.1	146.2	113.0
38	15.0	400	2.2	138.7	102.2	128.3	139.7	92.0
39	15.0	400	4.2	118.3	87.9	115.1	130.7	69.5
40	15.0	600	0.2	160.9	136.8	163.0	166.0	131.3
41	15.0	600	2.2	149.3	120.6	143.4	147.6	112.8
42	15.0	600	4.2	133.8	105.5	123.2	141.5	95.4
43	15.0	800	0.2	204.5	183.6	201.7	212.0	182.3
44	15.0	800	2.2	187.9	134.1	183.2	197.1	169.1
45	15.0	800	4.2	165.2	106.7	159.5	181.3	134.5
46	15.0	1000	0.2	233.5	210.0	224.3	240.8	200.2
47	15.0	1000	2.2	213.8	189.6	208.0	222.6	186.5
48	15.0	1000	4.2	199.8	176.7	190.6	210.0	172.1

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.

(b) Lbs H_2O/lb dry air x 100.

(c) Total Radiation Pyrometer (Rayotube), Btu/ft^2/hr x 10^{-3}.

TABLE 7

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON FLAME RADIATION (a)
(Prevaporized Fuels)

Test Cond. No.	Comb. Pres., atm	Inlet Air Temp., F	Heat Input, Btu/ lb air	Inlet Air Humid., % (b)	Flame Radiation With Fuels (c) A BJ-67 -9-G7	B BJ-67 -9-A5	C BJ-67 -9-G12	D BJ-67 -9-G4	E BJ-71 -8-A1
49	10.0	600	150	0.2	21.5	20.9	21.9	22.2	21.1
53	10.0	600	150	2.2	22.2	20.2	22.3	23.2	21.4
57	10.0	600	150	4.2	20.3	19.0	19.6	19.8	19.1
50	10.0	800	150	0.2	21.8	20.6	21.6	11.0	21.6
54	10.0	800	150	2.2	19.9	18.8	19.8	18.4	19.5
58	10.0	800	150	4.2	19.6	19.1	20.3	20.7	19.7
51	12.5	600	150	0.2	22.5	22.0	23.6	27.2	41.9
55	12.5	600	150	2.2	29.4	26.5	42.1	30.8	48.5
59	12.5	600	150	4.2	22.3	30.6	44.0	22.7	69.3
52	12.5	800	150	0.2	23.6	23.4	33.3	24.9	24.6
56	12.5	800	150	2.2	21.3	23.2	23.7	21.5	22.0
60	12.5	800	150	4.2	20.3	21.4	20.9	20.2	21.5
61	11.25	700	225	2.2	76.9	56.3	104.9	88.0	68.4
66	7.5	700	225	2.2	60.7	41.1	56.7	68.5	48.9
67	15.0	700	225	2.2	125.7	128.9	85.9	114.1	76.1
68	11.25	400	225	2.2	86.5	58.1	79.5	99.7	75.2
69	11.25	1000	225	2.2	67.9	58.0	76.7	76.5	61.9
64	11.25	700	225	0.2	92.4	65.6	91.5	98.6	85.0
65	11.25	700	225	4.2	57.0	43.8	90.7	40.2	51.4
63	11.25	700	100	2.2	10.9	10.8	11.0	10.7	10.9
62	11.25	700	350	2.2	238.9	151.1	179.9	250.2	199.2

(a) Reference Velocity = 140 ft/sec.
(b) Lbs H_2O/lb dry air x 100.
(c) Total Radiation Pyrometer (Rayotube), Btu/ft^2/hr x 10^{-3}.

TABLE 8

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON FLAME RADIATION (a)
(Pressure Atomized Fuel)

Test Cond. No.	Comb. Pres., atm	Inlet Air Temp., F	Heat Input, Btu/ lb air	Inlet Air Humid., % (b)	Flame Radiation with Fuels (c) A BJ-67 -9-G7	B BJ-67 -9-A5	C BJ-67 -9-G12	D BJ-67 -9-G4	E BJ-71 -8-A1
49	10.0	600	150	0.2	111.0	76.4	111.8	123.3	71.9
53	10.0	600	150	2.2	90.7	62.6	89.4	108.8	58.7
57	10.0	600	150	4.2	66.9	46.6	65.6	79.2	44.1
50	10.0	800	150	0.2	72.5	52.9	74.7	72.0	52.7
54	10.0	800	150	2.2	58.5	47.8	61.8	64.1	48.9
58	10.0	800	150	4.2	54.3	44.4	54.4	58.5	43.6
51	12.5	600	150	0.2	123.1	85.5	131.3	150.3	84.9
55	12.5	600	150	2.2	98.1	71.8	102.5	123.9	69.6
59	12.5	600	150	4.2	80.8	56.3	84.4	100.4	55.3
52	12.5	800	150	0.2	106.1	77.9	102.0	132.7	72.7
56	12.5	800	150	2.2	80.0	57.9	80.8	93.8	59.5
60	12.5	800	150	4.2	69.4	52.4	69.8	77.2	55.8
61	11.25	700	225	2.2	176.5	120.2	171.4	196.9	113.7
66	7.5	700	225	2.2	89.3	51.8	89.0	114.8	49.9
67	15.0	700	225	2.2	201.4	164.6	192.2	217.8	157.2
68	11.25	400	225	2.2	119.9	80.7	116.7	143.4	68.9
69	11.25	1000	225	2.2	175.8	122.5	170.6	200.4	126.5
64	11.25	700	225	0.2	198.6	152.1	197.6	222.1	144.2
65	11.25	700	225	4.2	147.9	99.1	141.7	174.0	94.7
63	11.25	700	100	2.2	31.9	31.5	33.6	30.3	33.9
62	11.25	700	350	2.2	144.4	113.8	133.6	159.7	100.7

(a) Reference Velocity = 140 ft/sec.
(b) Lbs H_2O/lb dry air x 100.
(c) Total Radiation Pyrometer (Rayotube), Btu/ft^2/hr x 10^{-3}.

TABLE 9

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON EXHAUST SMOKE (a)
(Program 1)

Test Cond. No.	Combustor Pressure, atm	Inlet Air Temp., F	Inlet Air Humidity, % (b)	Smoke Optical Density With Fuels (c) A BJ-67 -9-G7	B BJ-67 -9-A5	C BJ-67 -9-G12	D BJ-67 -9-G4	E BJ-71 -8-A1
1	7.5	400	0.2	0.292	0.174	0.208	0.351	0.100
2	7.5	400	2.2	0.045	0.000	0.000	0.397	0.000
3	7.5	400	4.2	0.000	0.084	0.031	0.364	0.043
4	7.5	600	0.2	0.072	0.088	0.092	0.016	0.003
5	7.5	600	2.2	0.186	0.050	0.138	0.115	0.052
6	7.5	600	4.2	0.204	0.168	0.265	0.338	0.060
7	7.5	800	0.2	0.171	0.101	0.154	0.184	0.061
8	7.5	800	2.2	0.169	0.141	0.174	0.219	0.063
9	7.5	800	4.2	0.572	0.070	0.114	0.193	0.027
10	7.5	1000	0.2	0.064	0.031	0.049	0.054	0.014
11	7.5	1000	2.2	0.000	0.030	0.048	0.071	0.020
12	7.5	1000	4.2	0.072	0.040	0.062	0.108	0.027
13	10.0	400	0.2	0.220	0.105	0.202	0.282	0.082
14	10.0	400	2.2	0.190	0.076	0.196	0.253	0.072
15	10.0	400	4.2	0.116	0.044	0.107	0.178	0.060
16	10.0	600	0.2	0.268	0.209	0.210	0.320	0.059
17	10.0	600	2.2	0.324	0.208	0.276	0.300	0.180
18	10.0	600	4.2	0.310	0.176	0.226	0.330	0.082
19	10.0	800	0.2	0.172	0.144	0.162	0.021	0.111
20	10.0	800	2.2	0.210	0.168	0.200	0.230	0.100
21	10.0	800	4.2	0.258	0.170	0.220	0.282	0.094
22	10.0	1000	0.2	0.030	0.011	0.046	0.080	0.014
23	10.0	1000	2.2	0.048	0.026	0.057	0.071	0.021
24	10.0	1000	4.2	0.052	0.033	0.052	0.072	0.007

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.

(b) Lbs H_2O/lb dry air x 100.

(c) Von Brand Smokemeter.

TABLE 9 (Continued)

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON EXHAUST SMOKE (a)
(Program 1)

Test Cond. No.	Combustor Pressure, atm	Inlet Air Temp., F	Inlet Air Humidity, % (b)	Smoke Optical Density With Fuels (c) A BJ-67-9-G7	B BJ-67-9-A5	C BJ-67-9-G12	D BJ-67-9-G4	E BJ-71-8-A1
25	12.5	400	0.2	0.390	0.153	0.240	0.300	0.145
26	12.5	400	2.2	0.236	0.106	0.222	0.282	0.114
27	12.5	400	4.2	0.078	0.072	0.202	0.250	0.024
28	12.5	600	0.2	0.224	0.108	0.193	0.218	0.110
29	12.5	600	2.2	0.182	0.077	0.148	0.178	0.074
30	12.5	600	4.2	0.110	0.031	0.122	0.161	0.058
31	12.5	800	0.2	0.157	0.182	0.133	0.172	0.066
32	12.5	800	2.2	0.005	0.150	0.187	0.185	0.127
33	12.5	800	4.2	0.170	0.187	0.234	0.228	0.102
34	12.5	1000	0.2	0.009	0.007	0.006	0.014	0.004
35	12.5	1000	2.2	0.037	0.043	0.013	0.016	0.019
36	12.5	1000	4.2	0.030	0.015	0.035	0.040	0.012
37	15.0	400	0.2	0.525	0.432	0.440	0.555	0.332
38	15.0	400	2.2	0.450	0.360	0.445	0.520	0.298
39	15.0	400	4.2	0.500	0.400	0.545	0.660	0.370
40	15.0	600	0.2	0.490	0.445	0.465	0.590	0.370
41	15.0	600	2.2	0.490	0.395	0.455	0.580	0.335
42	15.0	600	4.2	0.430	0.349	0.418	0.475	0.304
43	15.0	800	0.2	0.200	0.123	0.175	0.197	0.063
44	15.0	800	2.2	0.165	0.076	0.147	0.158	0.158
45	15.0	800	4.2	0.125	0.044	0.118	0.152	0.060
46	15.0	1000	0.2	0.015	0.044	0.005	0.000	0.000
47	15.0	1000	2.2	0.000	0.037	0.000	0.051	0.025
48	15.0	1000	4.2	0.051	0.032	0.049	0.070	0.018

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.

(b) Lbs H_2O/lb dry air x 100.

(c) Von Brand Smokemeter.

TABLE 10

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON EXHAUST SMOKE (a)
(Prevaporized Fuels)

Test Cond. No.	Comb. Pres., atm	Inlet Air Temp., F	Heat Input, Btu/lb air	Inlet Air Humid., % (b)	Smoke Optical Density With Fuels (c) A BJ-67-9-G7	B BJ-67-9-A5	C BJ-67-9-G12	D BJ-67-9-G4	E BJ-71-8-A1
49	10.0	600	150	0.2	0.062	0.052	0.056	0.075	0.040
53	10.0	600	150	2.2	0.066	0.034	0.054	0.073	0.042
57	10.0	600	150	4.2	0.013	0.004	0.000	0.056	0.000
50	10.0	800	150	0.2	0.019	0.002	0.007	0.021	0.003
54	10.0	800	150	2.2	0.014	0.006	0.012	0.014	0.003
58	10.0	800	150	4.2	0.017	0.003	0.025	0.036	0.006
51	12.5	600	150	0.2	0.068	0.041	0.030	0.084	0.082
55	12.5	600	150	2.2	0.145	0.075	0.140	0.080	0.170
59	12.5	600	150	4.2	0.100	0.100	0.210	0.100	0.260
52	12.5	800	150	0.2	0.038	0.026	0.043	0.060	0.027
56	12.5	800	150	2.2	0.018	0.010	0.015	0.027	0.011
60	12.5	800	150	4.2	0.019	0.013	0.016	0.017	0.012
61	11.25	700	225	2.2	0.163	0.135	0.285	0.176	0.142
66	7.5	700	225	2.2	0.188	0.085	0.168	0.190	0.126
67	15.0	700	225	2.2	0.238	0.290	0.124	0.200	0.125
68	11.25	400	225	2.2	0.252	0.150	0.320	0.300	0.222
69	11.25	1000	225	2.2	0.053	0.038	0.040	0.035	0.036
64	11.25	700	225	0.2	0.168	0.125	0.140	0.152	0.150
65	11.25	700	225	4.2	0.146	0.080	0.258	0.069	0.130
63	11.25	700	100	2.2	0.007	0.003	0.005	0.005	0.006
62	11.25	700	350	2.2	0.320	0.135	0.188	0.345	0.255

(a) Reference Velocity = 140 ft/sec.
(b) Lbs H_2O/lb dry air x 100.
(c) Von Brand Smokemeter.

TABLE 11

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON EXHAUST SMOKE (a)
(Pressure Atomized Fuel)

Test Cond. No.	Comb. Pres., atm	Inlet Air Temp., F	Heat Input, Btu/ lb air	Inlet Air Humid., % (b)	Smoke Optical Density With Fuels (c) A BJ-67 -9-G7	B BJ-67 -9-A5	C BJ-67 -9-G12	D BJ-67 -9-G4	E BJ-71 -8-A1
49	10.0	600	150	0.2	0.025	0.008	0.026	0.028	0.006
53	10.0	600	150	2.2	0.025	0.014	0.023	0.038	0.005
57	10.0	600	150	4.2	0.000	0.010	0.010	0.025	0.000
50	10.0	800	150	0.2	0.000	0.000	0.000	0.000	0.000
54	10.0	800	150	2.2	0.000	0.000	0.000	0.000	0.000
58	10.0	800	150	4.2	0.000	0.000	0.000	0.000	0.000
51	12.5	600	150	0.2	0.016	0.004	0.018	0.018	0.006
55	12.5	600	150	2.2	0.016	0.005	0.010	0.028	0.002
59	12.5	600	150	4.2	0.026	0.004	0.018	0.038	0.004
52	12.5	800	150	0.2	0.000	0.003	0.005	0.006	0.000
56	12.5	800	150	2.2	0.004	0.000	0.005	0.003	0.000
60	12.5	800	150	4.2	0.000	0.000	0.000	0.002	0.005
61	11.25	700	225	2.2	0.108	0.046	0.097	0.104	0.032
66	7.5	700	225	2.2	0.014	0.004	0.005	0.016	0.005
67	15.0	700	225	2.2	0.094	0.087	0.100	0.132	0.058
68	11.25	400	225	2.2	0.191	0.102	0.143	0.200	0.082
69	11.25	1000	225	2.2	0.004	0.000	0.004	0.007	0.004
64	11.25	700	225	0.2	0.090	0.040	0.074	0.092	0.042
65	11.25	700	225	4.2	0.076	0.030	0.084	0.086	0.023
63	11.25	700	100	2.2	0.000	0.000	0.000	0.000	0.000
62	11.25	700	350	2.2	0.320	0.260	0.310	0.370	0.220

(a) Reference Velocity = 140 ft/sec.
(b) Lbs H_2O/lb dry air x 100.
(c) Von Brand Smokemeter.

TABLE 12

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON EMISSIONS (a)
(Program 1)

Test Cond. No.	Comb. Pres., atm	Inlet Air Temp., F	Inlet Air Humid., % (b)	Fuel	Raw Sample CO_2, PPM	Emissions in Diluted Exhaust Gas, Concentration in PPM (c) CO_2	CO	(d) NO	(d) NO_x	(e) HC
1	7.5	400	0.2	A	32,200	12,500	75.4	17.3	20.6	0
				B	31,900	11,900	68.7	15.4	19.8	0.1
				C	33,300	12,600	71.4	16.2	20.6	1.5
				D	33,000	12,600	77.0	18.0	20.3	1.1
				E	30,100	11,300	58.0	14.8	19.8	0
2	7.5	400	2.2	A	33,000	12,800	77.6	11.5	14.7	1.1
				B	31,500	13,200	74.1	10.0	14.2	1.0
				C	32,800	12,800	78.6	11.3	15.1	1.0
				D	33,100	11,800	81.0	12.7	13.5	0
				E	30,400	11,400	66.7	10.3	14.3	1.0
3	7.5	400	4.2	A	31,900	12,000	72.2	8.5	11.9	1.4
				B	32,200	12,000	88.0	7.8	10.9	2.1
				C	32,500	12,500	76.5	9.1	11.9	1.4
				D	32,500	12,500	85.6	11.0	11.3	1.4
				E	30,400	11,440	64.8	10.1	10.8	1.6
4	7.5	600	0.2	A	30,900	11,500	37.4	25.9	32.1	0
				B	31,100	11,100	44.7	23.3	29.2	0
				C	30,800	11,300	45.9	23.5	30.1	0
				D	30,800	11,500	44.4	27.0	31.3	0.3
				E	28,400	10,400	37.1	23.1	29.2	0
5	7.5	600	2.2	A	32,400	12,100	44.2	17.7	21.4	0
				B	29,700	11,300	39.1	16.9	21.4	0
				C	31,400	11,800	42.4	18.6	23.0	1.0
				D	30,800	11,300	141.9	12.0	21.4	9.4
				E	29,100	11,100	35.2	17.9	21.8	1.0
6	7.5	600	4.2	A	30,500	11,500	40.3	13.2	16.0	1.1
				B	28,600	11,200	36.8	12.1	15.6	1.2
				C	29,600	11,600	42.7	12.7	15.8	0
				D	30,300	11,200	257.9	13.0	15.5	39.7
				E	27,900	11,700	33.0	11.9	15.6	1.0

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.
(b) Lbs H_2O/lb dry air x 100.
(c) Diluted with 2-parts N_2 per 1-part of exhaust gas.
(d) Measured as NO.
(e) Measured as carbon.

TABLE 12 (Continued)

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON EMISSIONS (a)
(Program 1)

Test Cond. No.	Comb. Pres., atm	Inlet Air Temp., F	Inlet Air Humid., % (b)	Fuel	Raw Sample CO_2, PPM	Emissions in Diluted Exhaust Gas, Concentration in PPM (c) CO_2	CO	(d) NO	(d) NO_x	(e) HC
7	7.5	800	0.2	A	30,700	11,700	24.2	44.3	47.9	0
				B	30,200	11,400	23.5	43.6	47.6	0
				C	32,300	12,100	24.5	47.0	51.2	0
				D	31,500	12,100	24.5	47.0	50.6	0
				E	28,900	11,080	23.0	44.7	48.2	0
8	7.5	800	2.2	A	31,600	11,700	24.6	35.1	38.7	0
				B	30,600	11,400	23.8	32.1	35.2	0
				C	32,200	12,100	25.2	34.4	37.9	0
				D	31,900	12,100	26.5	35.4	37.9	0
				E	29,500	11,000	26.5	32.9	35.8	0
9	7.5	800	4.2	A	31,400	12,120	22.5	25.9	26.1	0.2
				B	30,900	11,300	21.0	23.8	24.6	0
				C	31,600	11,200	22.4	25.1	26.6	0
				D	32,800	12,100	22.7	25.2	26.2	0
				E	29,000	11,000	21.0	23.6	25.3	0
10	7.5	1000	0.2	A	31,200	12,600	19.0	89.1	91.4	0
				B	29,800	12,100	12.3	88.3	93.8	0
				C	31,600	12,700	10.0	96.8	101.6	0
				D	31,900	12,700	9.5	97.4	101.3	0
				E	28,800	11,800	10.0	90.3	96.9	0
11	7.5	1000	2.2	A	30,800	12,600	15.7	65.8	68.5	0
				B	30,600	12,300	17.4	64.7	66.4	0
				C	31,500	12,800	15.2	67.8	69.8	0
				D	30,700	12,300	19.7	68.1	70.2	0
				E	28,800	11,400	20.1	64.9	67.2	0
12	7.5	1000	4.2	A	31,600	12,100	17.9	39.9	42.5	0
				B	30,300	11,900	20.6	38.3	40.1	0
				C	31,600	12,500	20.8	41.7	42.6	0
				D	31,900	12,400	20.5	40.9	42.4	0
				E	29,800	11,200	20.8	39.4	41.3	0

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.
(b) Lbs H_2O/lb dry air x 100.
(c) Diluted with 2-parts N_2 per 1-part of exhaust gas.
(d) Measured as NO.
(e) Measured as carbon.

TABLE 12 (Continued)

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON EMISSIONS (a)
(Program 1)

Test Cond. No.	Comb. Pres., atm	Inlet Air Temp., F	Inlet Air Humid., % (b)	Fuel	Raw Sample CO_2, PPM	Emissions in Diluted Exhaust Gas, Concentration in PPM (c) CO_2	CO	(d) NO	(d) NO_x	(e) HC
13	10.0	400	0.2	A	31,000	11,300	33.8	18.9	22.7	1.0
				B	30,400	11,800	35.4	16.6	21.3	0
				C	31,300	11,800	37.8	16.6	21.5	0
				D	32,400	12,260	43.6	18.8	22.0	0.3
				E	28,500	10,800	30.0	16.7	21.0	0
14	10.0	400	2.2	A	30,200	12,900	56.4	13.2	15.0	1.2
				B	28,400	11,000	50.8	11.1	13.8	1.2
				C	32,800	12,500	59.0	12.0	14.3	1.2
				D	30,800	13,100	62.5	14.4	16.4	1.2
				E	29,200	11,100	49.9	11.1	14.1	1.2
15	10.0	400	4.2	A	30,800	12,780	59.7	11.3	11.1	1.7
				B	29,800	12,600	80.5	10.2	11.1	3.5
				C	30,600	11,700	65.9	9.4	10.6	1.6
				D	31,700	12,000	72.5	9.8	11.0	1.8
				E	28,400	11,300	52.8	10.0	10.2	1.3
16	10.0	600	0.2	A	30,800	12,800	38.0	31.4	32.9	1.0
				B	30,100	12,800	35.6	27.0	32.1	1.0
				C	31,700	13,300	33.7	32.5	35.9	1.0
				D	31,700	13,500	42.3	34.5	34.5	1.0
				E	29,500	12,500	27.4	30.3	33.7	1.0
17	10.0	600	2.2	A	31,500	13,000	37.7	21.9	24.3	1.1
				B	30,500	13,500	32.7	22.7	23.9	1.0
				C	32,300	13,300	37.8	21.9	24.2	1.0
				D	31,700	13,300	38.2	23.9	24.1	1.0
				E	29,000	12,200	30.7	20.1	23.2	1.0
18	10.0	600	4.2	A	31,000	12,900	32.7	15.3	16.9	1.0
				B	31,000	12,600	33.0	13.6	16.1	1.1
				C	31,900	13,200	34.5	17.0	17.5	1.0
				D	31,500	13,000	36.4	17.4	17.5	1.0
				E	29,700	12,000	28.0	15.4	16.2	1.1

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.
(b) Lbs H_2O/lb dry air x 100.
(c) Diluted with 2-parts of N_2 per 1-part of exhaust gas.
(d) Measured as NO.
(e) Measured as carbon.

TABLE 12 (Continued)

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON EMISSIONS (a)
(Program 1)

Test Cond. No.	Comb. Pres., atm	Inlet Air Temp., F	Inlet Air Humid., % (b)	Fuel	Raw Sample CO_2, PPM	Emissions in Diluted Exhaust Gas, Concentration in PPM (c) CO_2	CO	(d) NO	(d) NO_x	(e) HC
19	10.0	800	0.2	A	32,000	12,400	15.0	52.0	51.3	0.2
				B	29,300	11,300	14.8	51.2	53.8	0
				C	32,500	12,400	18.8	52.3	53.8	0
				D	31,400	12,300	16.1	53.0	53.5	0
				E	29,100	11,300	16.8	48.7	51.4	0
20	10.0	800	2.2	A	32,600	12,800	20.5	37.6	39.8	0
				B	30,600	11,900	20.4	36.7	37.9	0
				C	32,700	12,800	20.8	40.8	41.0	0
				D	32,600	12,700	21.0	41.3	41.7	0
				E	30,100	11,900	18.0	37.7	39.6	0
21	10.0	800	4.2	A	32,000	12,300	17.0	25.9	27.2	0
				B	31,400	11,800	17.0	26.0	26.2	0
				C	33,900	12,700	19.3	28.1	29.1	0
				D	33,500	12,900	18.7	27.5	27.0	0
				E	29,900	11,500	16.4	26.8	27.0	0
22	10.0	1000	0.2	A	28,100	12,200	15.2	90.2	96.4	1.1
				B	27,000	11,600	12.8	84.4	90.2	1.1
				C	30,600	12,900	13.8	97.1	102.3	1.0
				D	34,200	14,700	12.0	104.0	109.2	1.0
				E	27,000	11,400	12.3	86.6	93.4	1.0
23	10.0	1000	2.2	A	29,900	12,400	13.2	66.2	69.9	1.0
				B	29,300	12,200	11.9	65.5	68.7	0
				C	30,500	12,100	12.1	68.7	72.4	0.7
				D	30,600	12,300	12.4	71.0	73.3	0
				E	28,000	11,800	12.5	66.0	69.2	0
24	10.0	1000	4.2	A	29,500	12,700	11.1	48.9	53.1	1.0
				B	29,200	12,000	11.1	46.7	49.9	0.3
				C	31,000	12,900	11.7	51.5	53.4	0
				D	31,000	12,900	12.1	51.3	53.0	0.3
				E	28,000	11,600	11.5	46.0	49.0	0

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.
(b) Lbs H_2O/lb dry air x 100.
(c) Diluted with 2-parts N_2 per 1-part of exhaust gas.
(d) Measured as NO.
(e) Measured as carbon.

TABLE 12 (Continued)

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON EMISSIONS (a)
(Program 1)

Test Cond. No.	Comb. Pres., atm	Inlet Air Temp., F	Inlet Air Humid., % (b)	Fuel	Raw Sample CO_2, PPM	Emissions in Diluted Exhaust Gas, Concentration in PPM (c) CO_2	CO	(d) NO	(d) NO_x	(e) HC
25	12.5	400	0.2	A	31,500	13,100	69.9	20.7	24.0	1.2
				B	31,500	12,600	39.5	19.0	23.3	1.1
				C	31,800	13,000	58.6	21.7	24.2	1.1
				D	33,000	13,200	40.2	22.2	25.3	1.1
				E	30,000	12,000	31.6	18.8	23.1	1.1
26	12.5	400	2.2	A	31,800	12,800	49.8	15.1	17.3	1.1
				B	32,100	13,100	55.1	13.2	16.1	0
				C	32,000	13,300	53.7	15.1	16.9	0
				D	32,100	13,500	55.0	15.7	17.1	0
				E	29,800	12,500	44.6	13.6	16.0	0
27	12.5	400	4.2	A	30,500	13,200	60.5	11.9	12.2	1.4
				B	29,800	12,200	62.1	11.2	11.6	1.4
				C	30,200	11,500	61.3	10.8	12.5	1.2
				D	31,300	12,900	66.6	11.3	12.8	1.2
				E	28,200	11,800	52.1	10.8	11.8	1.3
28	12.5	600	0.2	A	33,100	13,900	25.7	39.1	42.5	1.2
				B	30,600	13,300	25.2	37.0	41.0	1.1
				C	32,400	13,800	26.4	38.1	43.0	1.1
				D	32,800	14,100	26.5	42.3	45.1	1.2
				E	29,200	12,600	25.1	35.2	39.2	0.1
29	12.5	600	2.2	A	30,900	13,500	43.4	25.3	28.4	0
				B	30,300	13,100	34.2	25.4	28.5	0
				C	30,900	13,100	46.6	27.1	29.6	1.1
				D	32,300	13,800	45.0	29.3	31.2	0
				E	28,100	12,000	43.5	24.1	26.7	0
30	12.5	600	4.2	A	30,900	13,100	31.0	19.3	20.9	0
				B	29,800	12,600	34.2	17.6	19.4	0
				C	30,600	13,100	36.3	18.7	20.9	0
				D	32,300	13,800	39.0	20.5	21.3	0
				E	28,400	12,000	34.5	16.7	18.8	0

(a) Reference Velocity = 1[illegible]0 ft/sec.
Heat Input = 300 Btu/lb air.
(b) Lbs H_2O/lb dry air x 100.
(c) Diluted with 2-parts N_2 per 1-part exhaust gas.
(d) Measured as NO.
(e) Measured as carbon.

TABLE 12 (Continued)

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON EMISSIONS (a)
(Program 1)

Test Cond. No.	Comb. Pres., atm	Inlet Air Temp., F	Inlet Air Humid., % (b)	Fuel	Raw Sample CO_2, PPM	Emissions in Diluted Exhaust Gas, Concentration in PPM (c)				
						CO_2	CO	(d) NO	(d) NO_x	(e) HC
31	12.5	800	0.2	A	32,200	12,800	14.5	55.6	61.7	0
				B	32,200	12,500	13.4	56.1	60.9	0
				C	32,800	13,000	15.9	59.5	62.9	1.0
				D	32,800	12,800	16.4	59.5	62.2	0.9
				E	30,000	11,900	13.9	54.7	58.8	1.0
32	12.5	800	2.2	A	32,400	12,600	13.3	41.5	42.2	0
				B	31,600	12,300	16.2	37.9	38.5	0
				C	32,900	12,500	16.5	39.6	41.4	0
				D	32,900	12,900	17.1	40.4	41.3	0
				E	31,900	12,[illegible]	13.5	36.7	40.1	0
33	12.5	800	4.2	A	33,000	12,600	14.9	29.7	30.0	0
				B	31,600	12,300	15.9	27.4	28.5	0
				C	32,800	11,600	19.1	26.0	26.4	0
				D	33,300	11,000	17.7	27.1	26.9	0
				E	30,900	10,700	14.3	25.7	26.3	0
34	12.5	1000	0.2	A	32,200	13,100	12.2	113.4	123.5	0.1
				B	31,600	12,800	8.4	110.3	122.7	0
				C	32,200	13,100	9.3	121.8	128.2	0.2
				D	32,200	13,100	10.9	124.3	126.0	0.2
				E	29,700	12,200	8.1	108.1	114.8	0
35	12.5	1000	2.2	A	31,900	12,800	11.2	74.1	78.5	0
				B	31,500	12,300	13.1	64.4	68.8	0
				C	32,700	12,600	12.2	70.6	74.2	0
				D	32,800	12,900	11.9	73.1	76.0	0
				E	29,200	11,100	12.9	64.4	70.2	0
36	12.5	1000	4.2	A	32,900	12,800	12.3	54.3	56.9	0
				B	31,700	12,300	13.6	49.3	53.9	0
				C	33,100	12,900	12.0	56.3	58.3	0
				D	33,100	13,200	12.2	58.2	59.4	0
				E	30,400	11,800	12.0	49.1	52.7	0

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.
(b) Lbs H_2O/lb dry air x 100.
(c) Diluted with 2-parts N_2 per 1-part exhaust gas.
(d) Measured as NO.
(e) Measured as carbon.

TABLE 12 (Continued)

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON EMISSIONS (a)
(Program 1)

Test Cond. No.	Comb. Pres., atm	Inlet Air Temp., F	Inlet Air Humid., % (b)	Fuel	Raw Sample CO_2, PPM	Emissions in Diluted Exhaust Gas, Concentration in PPM (c) CO_2	CO	(d) NO	(d) NO_x	(e) HC
37	15.0	400	0.2	A	30,100	10,500	46.5	22.4	21.4	0
				B	30,100	10,500	41.6	21.7	21.5	0
				C	29,100	10,100	39.8	22.2	21.8	0
				D	31,000	10,500	51.1	21.7	21.2	0
				E	28,300	9,500	32.6	22.0	21.7	0
38	15.0	400	2.2	A	29,800	10,500	62.8	15.8	16.0	0.4
				B	29,100	10,200	48.9	15.8	15.9	0
				C	29,700	10,200	47.2	16.0	16.1	0
				D	30,800	10,500	57.9	16.1	15.9	0
				E	28,400	9,900	43.4	15.2	16.0	0
39	15.0	400	4.2	A	31,400	11,000	62.5	12.2	12.5	1.6
				B	30,800	10,200	63.5	12.1	11.7	1.5
				C	30,400	10,200	68.6	12.0	11.8	1.5
				D	31,500	10,500	83.8	11.7	11.4	1.7
				E	29,100	10,200	63.7	11.3	12.3	1.5
40	15.0	600	0.2	A	30,300	12,600	33.5	38.7	34.5	0
				B	30,900	12,500	34.2	36.5	36.3	0
				C	29,200	10,600	32.7	29.7	33.0	0
				D	31,000	7,940	28.8	26.9	24.1	0
				E	29,000	11,700	30.9	35.5	35.8	0
41	15.0	600	2.2	A	29,500	11,480	47.3	25.8	24.7	0
				B	30,600	12,200	50.0	24.8	25.8	0
				C	31,200	12,500	50.9	25.6	25.1	0
				D	31,600	13,000	56.3	26.4	26.1	0
				E	29,800	11,100	41.2	24.2	23.8	0
42	15.0	600	0.2	A	30,900	11,800	57.0	17.7	17.4	1.0
				B	30,600	11,500	53.7	16.1	15.7	0
				C	31,600	11,800	58.5	16.6	16.0	0
				D	32,300	11,800	61.0	17.2	16.4	0
				E	29,200	10,800	50.0	16.0	15.8	1.0

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.
(b) Lbs H_2O/lb dry air x 100.
(c) Diluted with 2-parts N_2 per 1-part exhaust gas.
(d) Measured as NO.
(e) Measured as carbon.

TABLE 12 (Continued)

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON EMISSIONS (a)
(Program 1)

Test Cond. No.	Comb. Pres., atm	Inlet Air Temp., F	Inlet Air Humid., % (b)	Fuel	Raw Sample CO_2, PPM	Emissions in Diluted Exhaust Gas, Concentration in PPM (c)				
						CO_2	CO	(d) NO	(d) NO_x	(e) HC
43	15.0	800	0.2	A	31,000	13,000	36.4	61.3	63.9	0
				B	31,200	13,340	30.7	65.1	68.8	0
				C	31,300	13,100	34.7	62.7	65.8	0
				D	33,400	13,900	36.7	68.6	72.1	0
				E	29,300	12,300	33.4	58.8	65.5	0
44	15.0	800	2.2	A	30,700	14,360	21.1	53.4	50.1	0
				B	29,400	12,400	21.5	45.3	46.9	0
				C	30,700	13,420	22.4	50.0	50.1	0
				D	33,400	14,100	21.5	51.6	52.2	0
				E	29,000	12,400	21.5	42.6	43.4	0
45	15.0	800	4.2	A	31,300	12,700	26.8	33.2	33.4	0
				B	30,000	12,500	32.6	31.0	32.7	0
				C	31,600	12,700	30.2	33.6	34.6	0
				D	32,400	13,500	31.1	35.2	36.0	0
				E	29,300	11,600	32.7	28.8	30.4	0
46	15.0	1000	0.2	A	33,700	14,400	9.3	124.8	127.8	0
				B	33,200	13,400	9.0	109.8	117.7	0
				C	34,600	14,300	9.1	124.2	131.6	1.1
				D	33,300	12,900	9.3	118.4	126.3	0.2
				E	30,100	11,900	9.5	110.4	118.9	0
47	15.0	1000	2.2	A	31,100	12,240	13.2	80.1	86.0	0
				B	31,200	12,200	15.4	73.0	79.5	0
				C	32,500	12,833	14.7	81.3	86.4	0
				D	33,300	12,560	16.1	83.8	85.2	0
				E	30,600	11,600	14.7	73.1	78.1	0
48	15.0	1000	4.2	A	33,000	12,500	10.4	58.9	61.5	0.2
				B	31,800	11,960	11.4	53.9	57.9	1.0
				C	33,400	12,560	11.5	58.1	60.4	1.0
				D	33,000	12,200	11.4	58.3	58.1	0.5
				E	30,000	11,400	10.7	53.8	56.2	0.6

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.
(b) Lbs H_2O/lb dry air x 100.
(c) Diluted with 2-parts N_2 per 1-part exhaust gas.
(d) Measured as NO.
(e) Measured as carbon.

TABLE 13

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON EMISSIONS (a)
(Prevaporized Fuels)

Test Cond. No.	Comb. Pres., atm	Inlet Air Temp., F	Heat Input, Btu/lb air	Inlet Air Humid., % (b)	Fuel	Emissions in Diluted Exhaust Gas, Concentration in PPM (c) CO_2	CO	(d) NO	(d) NO_x	(e) HC
49	10.0	600	150	0.2	A	7,280	16.8	25.0	27.1	0
					B	7,050	17.2	24.3	26.0	0
					C	7,280	17.2	25.5	27.2	0
					D	7,300	16.8	26.1	27.8	0
					E	7,280	16.8	24.0	26.0	0
53	10.0	600	150	2.2	A	7,120	27.6	17.3	17.8	1.3
					B	6,664	31.7	16.9	17.0	2.1
					C	7,035	28.9	17.3	18.2	1.1
					D	7,232	29.2	17.9	18.7	1.0
					E	6,957	29.8	15.9	17.2	1.8
57	10.0	600	150	4.2	A	7,099	45.6	11.4	12.1	0
					B	6,874	48.3	11.6	11.7	1.3
					C	7,029	49.5	11.4	12.0	0
					D	7,054	51.5	11.9	12.2	0.5
					E	6,858	49.0	10.6	11.3	1.1
50	10.0	800	150	0.2	A	7,065	17.6	41.3	44.3	0
					B	6,948	17.2	42.2	44.4	0
					C	7,090	17.1	42.6	45.7	0
					D	7,053	16.3	44.4	47.2	0
					E	7,025	17.1	41.2	43.9	0
54	10.0	800	150	2.2	A	6,285	19.0	22.0	23.3	0
					B	6,063	17.6	21.7	23.3	0
					C	6,250	17.5	22.9	24.2	0
					D	6,189	17.2	23.5	25.5	0
					E	6,210	18.0	20.9	22.6	0
58	10.0	800	150	4.2	A	6,139	30.8	15.4	16.0	0
					B	5,986	35.7	15.0	16.5	0
					C	6,307	32.8	15.9	17.0	0
					D	6,311	34.0	15.6	16.9	0
					E	6,246	34.0	14.8	15.7	0

(a) Reference Velocity = 140 ft/sec.
(b) Lbs H_2O/lb dry air x 100.
(c) Diluted with 2-parts N_2 per 1-part of exhaust gas.
(d) Measured as NO.
(e) Measured as carbon.

TABLE 13 (Continued)

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON EMISSIONS (a)
(Prevaporized Fuels)

Test Cond. No.	Comb. Pres., atm	Inlet Air Temp., F	Heat Input, Btu/lb air	Inlet Air Humid., % (b)	Fuel	Emissions in Diluted Exhaust Gas, Concentration in PPM (c) CO_2	CO	(d) NO	(d) NO_x	(e) HC
51	12.5	600	150	0.2	A	6,670	10.9	24.9	26.0	0
					B	6,315	11.4	25.3	26.4	0
					C	6,642	10.7	26.2	28.0	0
					D	6,521	11.6	25.6	26.5	0
					E	6,200	12.9	21.2	22.6	0
55	12.5	600	150	2.2	A	6,200	27.8	14.2	15.5	1.2
					B	6,010	28.8	14.0	14.6	0.6
					C	6,408	32.0	15.3	14.7	1.0
					D	6,236	25.8	16.0	16.5	0
					E	5,988	32.1	12.9	13.9	0
59	12.5	600	150	4.2	A	6,039	42.0	10.9	11.4	0
					B	5,753	49.1	10.1	10.1	0.4
					C	5,957	60.1	9.0	11.3	2.0
					D	6,094	43.6	11.5	11.8	0
					E	5,825	67.8	8.3	9.0	4.1
52	12.5	800	150	0.2	A	7,010	16.3	45.9	47.1	0
					B	6,860	15.8	44.0	45.5	0
					C	6,776	15.5	47.4	47.3	0
					D	7,169	15.5	47.8	49.3	0
					E	6,845	15.3	43.3	45.8	0
56	12.5	800	150	2.2	A	6,467	19.3	24.9	26.5	0
					B	6,348	18.9	24.2	25.1	0
					C	6,517	18.8	25.0	26.7	0
					D	6,561	18.0	25.4	27.5	0
					E	6,457	18.5	24.0	25.5	0
60	12.5	800	150	4.2	A	6,477	30.2	17.2	18.6	0
					B	6,214	31.0	15.5	16.7	0
					C	6,359	30.1	17.5	17.6	0
					D	6,353	28.8	18.0	19.3	0
					E	6,286	31.0	15.9	17.2	0

(a) Reference Velocity = 140 ft/sec.
(b) Lbs H_2O/lb dry air x 100.
(c) Diluted with 2-parts N_2 per 1-part of exhaust gas.
(d) Measured as NO.
(e) Measured as carbon.

TABLE 13 (Continued)

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON EMISSIONS (a)
(Prevaporized Fuels)

Test Cond. No.	Comb. Pres., atm	Inlet Air Temp., F	Heat Input, Btu/ lb air	Inlet Air Humid., % (b)	Fuel	Emissions in Diluted Exhaust Gas, Concentration in PPM (c)				
						CO_2	CO	(d) NO	(d) NO_x	(e) HC
61	11.25	700	225	2.2	A	9,169	27.5	22.5	23.2	0
					B	9,004	30.0	21.4	22.4	0
					C	9,014	36.7	20.3	21.8	0
					D	9,584	27.8	24.9	25.1	0
					E	9,069	30.0	22.6	23.6	0
66	7.5	700	225	2.2	A	9,344	24.1	18.7	20.6	0
					B	9,050	22.9	18.2	19.6	0
					C	9,374	26.5	19.6	20.6	0
					D	9,416	25.1	19.5	21.1	0
					E	9,190	26.5	19.2	20.7	0
67	15.0	700	225	2.2	A	8,816	44 0	27.0	33.8	0
					B	8,643	42.9	25.8	25.4	0
					C	8,800	37.9	25.8	26.0	0
					D	8,659	37.9	27.0	26.6	0
					E	8,709	39.1	24.4	24.3	0
68	11.25	400	225	2.2	A	8,967	50.4	12.7	13.4	0
					B	8,585	47.9	12.0	12.5	0
					C	8,395	73.0	11.9	11.8	4.7
					D	8,566	49.0	13.6	13.3	0
					E	8,739	60.6	12.0	13.3	1.3
69	11.25	1000	225	2.2	A	8,650	24.4	44.7	46.2	0
					B	8,511	27.6	43.1	44.7	0
					C	8,967	27.7	44.9	48.7	0
					D	9,023	24.9	47.5	47.3	0
					E	8,807	25.0	43.6	45.0	0
64	11.25	700	225	0.2	A	9,446	16.9	34.1	36.1	0
					B	8,640	15.8	30.5	32.4	0
					C	9,272	15.8	34.4	38.1	0
					D	9,342	16.3	35.6	37.1	0
					E	9,178	16.7	34.3	36.1	0

(a) Reference Velocity = 140 ft/sec.
(b) Lbs H_2O/lb dry air x 100.
(c) Diluted with 2-parts N_2 per 1-part of exhaust gas.
(d) Measured as NO.
(e) Measured as carbon.

TABLE 13 (Continued)

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON EMISSIONS (a)
(Prevaporized Fuels)

Test Cond. No.	Comb. Pres., atm	Inlet Air Temp., F	Heat Input, Btu/lb air	Inlet Air Humid., % (b)	Fuel	Emissions in Diluted Exhaust Gas, Concentration in PPM (c) CO_2	CO	(d) NO	(d) NO_x	(e) HC
65	11.25	700	225	4.2	A	9,041	65.3	16.4	16.4	0
					B	8,841	65.5	15.4	16.6	0
					C	9,164	83.6	13.7	15.7	1.3
					D	8,593	68.7	14.2	15.2	0
					E	8,910	65.8	15.7	16.6	0
63	11.25	700	100	2.2	A	4,788	45.4	22.5	23.6	0
					B	4,725	30.8	22.4	23.3	0
					C	4,849	30.5	22.3	23.1	0
					D	4,776	30.0	22.2	22.9	0
					E	4,796	33.2	21.8	22.2	0
62	11.25	700	350	2.2	A	14,339	44.7	42.8	42.5	0
					B	14,353	44.0	40.8	44.1	0
					C	14,200	52.7	39.7	40.0	0
					D	15,026	55.5	43.1	43.8	0
					E	14,186	48.5	40.2	43.2	0

(a) Reference Velocity = 140 ft/sec.
(b) Lbs H_2O/lb dry air x 100.
(c) Diluted with 2-parts N_2 per 1-part of exhaust gas.
(d) Measured as NO.
(e) Measured as carbon.

TABLE 14

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON EMISSIONS (a)
(Pressure Atomized Fuel)

Test Cond. No.	Comb. Pres., atm	Inlet Air Temp., F	Heat Input, Btu/ lb air	Inlet Air Humid., % (b)	Fuel	Emissions in Diluted Exhaust Gas, Concentration in PPM (c) CO_2	CO	(d) NO	(d) NO_x	(e) HC
49	10.0	600	150	0.2	A	5,867	7.5	18.3	19.0	0
					B	5,930	7.5	17.0	17.9	0
					C	5,947	7.5	18.1	19.1	0
					D	5,918	7.0	19.0	20.2	0
					E	5,841	7.5	17.0	18.1	0
53	10.0	600	150	2.2	A	5,678	13.4	11.1	11.5	0
					B	5,503	13.5	10.4	11.0	0
					C	5,711	13.0	11.6	12.1	0
					D	5,800	13.0	12.0	12.7	0
					E	5,600	13.5	10.8	11.3	0
57	10.0	600	150	4.2	A	6,950	25.9	9.5	10.0	0
					B	6,500	26.0	8.4	8.8	0
					C	6,533	27.9	8.5	9.0	0
					D	6,550	27.9	8.9	9.4	0
					E	6,500	27.2	7.9	8.7	0
50	10.0	800	150	0.2	A	6,730	6.8	38.8	40.0	0
					B	6,120	8.0	34.0	35.7	0
					C	6,370	7.7	35.6	36.9	0
					D	6,135	7.6	37.5	38.6	0
					E	6,184	8.2	33.8	35.2	0
54	10.0	800	150	2.2	A	6,209	11.0	24.9	26.2	0
					B	6,126	12.6	23.1	23.9	0
					C	6,294	13.0	23.8	25.2	0
					D	6,120	11.8	25.0	26.3	0
					E	6,292	12.2	23.1	24.0	0
58	10.0	800	150	4.2	A	6,230	22.7	15.6	16.5	0
					B	6,131	25.8	14.3	14.9	0
					C	6,286	27.3	15.2	16.1	0
					D	6,286	27.3	15.2	16.1	0
					E	6,277	27.0	14.8	16.8	0

(a) Reference Velocity = 140 ft/sec.
(b) Lbs H_2O/lb dry air x 100.
(c) Diluted with 2-parts N_2 per 1-part of exhaust gas.
(d) Measured as NO.
(e) Measured as carbon.

TABLE 14 (Continued)

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON EMISSIONS (a)
(Pressure Atomized Fuel)

Test Cond. No.	Comb. Pres., atm	Inlet Air Temp., F	Heat Input, Btu/ lb air	Inlet Air Humid., % (b)	Fuel	Emissions in Diluted Exhaust Gas, Concentration in PPM (c) CO_2	CO	(d) NO	(d) NO_x	(e) HC
51	12.5	600	150	0.2	A	6,900	11.2	22.4	23.6	0
					B	6,713	10.8	21.2	22.7	0
					C	6,950	10.8	22.4	23.5	0
					D	6,930	10.8	23.1	24.4	0
					E	6,850	11.6	20.9	22.6	0
55	12.5	600	150	2.2	A	5,754	13.8	12.0	12.2	0
					B	5,959	14.4	11.7	11.9	0
					C	6,120	14.0	12.4	12.7	0
					D	6,200	14.0	13.0	12.7	0
					E	6,105	14.2	11.9	12.1	0
59	12.5	600	150	4.2	A	6,000	20.7	9.5	9.1	0
					B	5,750	21.7	8.2	8.4	0
					C	6,080	22.2	8.5	8.8	0
					D	6,050	21.5	9.1	9.3	0
					E	5,940	21.7	8.2	8.5	0
52	12.5	800	150	0.2	A	6,983	8.1	42.4	42.9	0
					B	6,769	8.6	39.4	40.4	0
					C	6,824	9.0	41.3	43.2	0
					D	7,056	8.6	42.2	43.8	0
					E	6,707	8.8	38.6	40.7	0
56	12.5	800	150	2.2	A	5,555	13.7	23.1	23.6	0
					B	5,700	13.8	21.0	21.7	0
					C	5,900	12.5	22.9	23.1	0
					D	5,890	11.9	23.4	23.9	0
					E	5,592	13.8	20.8	20.8	0
60	12.5	800	150	4.2	A	5,700	22.5	14.4	14.8	0
					B	5,500	25.7	13.8	14.1	0
					C	5,600	24.5	14.9	14.7	0
					D	5,550	25.7	15.3	15.6	0
					E	6,050	30.1	17.5	17.8	0

(a) Reference Velocity = 140 ft/sec.
(b) Lbs H_2O/lb dry air x 100.
(c) Diluted with 2-parts N_2 per 1-part of exhaust gas.
(d) Measured as NO.
(e) Measured as carbon.

TABLE 14 (Continued)

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON EMISSIONS (a)
(Pressure Atomized Fuel)

Test Cond. No.	Comb. Pres., atm	Inlet Air Temp., F	Heat Input, Btu/lb air	Inlet Air Humid., % (b)	Fuel	Emissions in Diluted Exhaust Gas, Concentration in PPM (c) CO_2	CO	(d) NO	(d) NO_x	(e) HC
61	11.25	700	225	2.2	A	8,771	19.7	18.8	20.2	0
					B	8,000	18.9	17.7	19.3	0
					C	8,666	19.9	19.7	20.9	0
					D	8,430	20.2	19.6	21.2	0
					E	8,080	20.8	18.3	19.6	0
66	7.5	700	225	2.2	A	8,600	17.8	16.2	18.0	0
					B	8,380	17.9	15.8	16.5	0
					C	8,489	17.2	15.9	18.0	0
					D	9,090	17.3	17.4	19.7	0
					E	8,357	17.9	15.1	17.0	0
67	15.0	700	225	2.2	A	9,803	19.9	24.3	24.2	0
					B	9,364	22.1	21.7	22.2	0
					C	9,647	20.9	23.5	24.1	0
					D	9,903	21.4	24.3	24.8	0
					E	9,516	20.5	23.4	23.2	0
68	11.25	400	225	2.2	A	9,727	38.0	10.2	11.9	0
					B	9,470	36.2	9.8	10.4	0
					C	9,930	41.5	11.5	11.8	0
					D	9,960	40.4	11.2	12.0	0
					E	9,567	36.5	10.3	11.9	0
69	11.25	1000	225	2.2	A	9,260	15.9	41.3	44.4	0
					B	9,140	18.0	39.4	41.3	0
					C	9,223	17.8	42.5	44.4	0
					D	9,366	16.3	42.8	44.3	0
					E	9,189	16.4	40.4	42.6	0
64	11.25	700	225	0.2	A	9,390	16.4	32.6	34.7	0
					B	9,420	15.2	31.7	34.3	0
					C	9,923	15.2	34.4	37.0	0
					D	10,000	16.3	34.8	36.5	0
					E	9,670	16.3	33.5	36.1	0

(a) Reference Velocity = 140 ft/sec.
(b) Lbs H_2O/lb dry air x 100.
(c) Diluted with 2-parts N_2 per 1-part of exhaust gas.
(d) Measured as NO.
(e) Measured as carbon.

TABLE 14 (Continued)

DATA FOR EFFECT OF FUELS AND OPERATING VARIABLES ON EMISSIONS (a)
(Pressure Atomized Fuel)

Test Cond. No.	Comb. Pres., atm	Inlet Air Temp., F	Heat Input, Btu/lb air	Inlet Air Humid., % (b)	Fuel	Emissions in Diluted Exhaust Gas, Concentration in PPM (c) CO_2	CO	(d) NO	(d) NO_x	(e) HC
65	11.25	700	225	4.2	A	9,134	34.9	15.3	15.9	0
					B	8,840	36.0	14.3	15.4	0
					C	9,149	39.0	14.8	15.9	0
					D	9,309	39.5	15.6	16.3	0
					E	8,927	38.1	14.2	15.1	0
63	11.25	700	100	2.2	A	4,830	17.6	15.4	15.9	0
					B	4,800	17.0	15.0	15.9	0
					C	5,066	16.1	16.9	17.5	0
					D	4,789	16.3	15.2	15.9	0
					E	4,990	16.4	17.0	17.1	0
62	11.25	700	350	2.2	A	12,505	30.2	25.5	27.6	0
					B	14,200	39.3	28.7	30.6	0
					C	14,719	41.0	30.3	31.7	0
					D	14,300	38.6	30.3	31.3	0
					E	11,900	27.5	24.0	26.3	0

(a) Reference Velocity = 140 ft/sec.
(b) Lbs H_2O/lb dry air x 100.
(c) Diluted with 2-parts N_2 per 1-part of exhaust gas.
(d) Measured as NO.
(e) Measured as carbon.

TABLE 15

CALCULATED EMISSIONS WITH VARIATIONS IN FUELS AND OPERATING CONDITIONS (a)
(Program 1)

Test Cond. No.	Test Conds.	Test Fuel	Mass of Emissions, lbs/hr (b) NO_x	(b) NO	CO	(c) HC	Emission Index, lbs/1000-lbs fuel (b) NO_x	(b) NO	CO	(c) HC
1	$P_0\ T_0\ H_0$	A	0.278	0.233	0.619	0	5.38	4.52	12.0	0
		B	0.275	0.214	0.580	0.0006	5.39	4.19	11.4	0.01
		C	0.275	0.216	0.580	0.0060	5.34	4.20	11.3	0.12
		D	0.277	0.245	0.639	0.0044	5.29	4.69	12.2	0.08
		E	0.272	0.203	0.485	0	5.64	4.22	10.1	0
2	$P_0\ T_0\ H_1$	A	0.188	0.147	0.603	0.0043	3.75	2.94	12.1	0.01
		B	0.172	0.121	0.547	0.0039	3.48	2.45	11.1	0.01
		C	0.191	0.143	0.607	0.0040	3.84	2.88	12.2	0.08
		D	0.190	0.179	0.694	0	3.75	3.53	13.7	0
		E	0.188	0.136	0.535	0.0042	4.04	2.91	11.5	0.09
3	$P_0\ T_0\ H_2$	A	0.157	0.112	0.580	0.0056	3.24	2.31	12.0	0.12
		B	0.141	0.101	0.692	0.0083	2.94	2.10	14.4	0.17
		C	0.150	0.114	0.587	0.0054	3.11	2.37	12.2	0.11
		D	0.146	0.142	0.671	0.0055	2.96	2.89	13.7	0.11
		E	0.138	0.129	0.503	0.0063	3.04	2.84	11.1	0.14
4	$P_0\ T_1\ H_0$	A	0.383	0.309	0.272	0	9.14	7.38	6.49	0
		B	0.353	0.282	0.329	0	8.53	6.81	7.95	0
		C	0.364	0.284	0.338	0	8.70	6.80	8.08	0
		D	0.377	0.325	0.326	0.0010	8.95	7.72	7.73	0.02
		E	0.355	0.281	0.275	0	9.06	7.16	7.00	0
5	$P_0\ T_1\ H_1$	A	0.235	0.194	0.296	0	5.79	4.79	7.28	0
		B	0.246	0.195	0.274	0	6.14	4.85	6.84	0
		C	0.258	0.208	0.289	0.0034	6.38	5.16	7.16	0.08
		D	0.254	0.142	1.024	0.0337	6.17	3.46	24.9	0.82
		E	0.240	0.197	0.236	0.0034	6.34	5.20	6.23	0.09
6	$P_0\ T_1\ H_2$	A	0.179	0.148	0.329	0.0037	4.55	3.76	8.37	0.10
		B	0.176	0.136	0.252	0.0042	4.52	3.50	6.49	0.11
		C	0.175	0.140	0.287	0	4.46	3.58	7.33	0
		D	0.177	0.149	1.795	0.1374	4.45	3.73	45.1	3.45
		E	0.173	0.132	0.223	0.0034	4.70	3.59	6.06	0.09

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.
Combustor Pressure, P_0 = 7.5 atm.
Inlet Air Temperature, T_0 = 400 F, T_1 = 600 F.
Inlet Air Humidity, H_0 = 0.2, H_1 = 2.2, H_2 = 4.2 lbs H_2O/lb dry air x 100.
(b) Calculated as NO_2
(c) Calculated as Carbon.

TABLE 1? (Continued)

CALCULATED EMISSION WITH VARIATIONS IN FUELS AND OPERATING CONDITIONS (a)
(Program 1)

Test Cond. No.	Test Conds.	Test Fuel	Mass of Emissions, lbs/hr (b) NO_x	(b) NO	CO	(c) HC	Emission Index, lbs/1000-lbs fuel (b) NO_x	(b) NO	CO	(c) HC
7	$P_0\ T_2\ H_0$	A	0.473	0.437	0.145	0	13.4	12.4	4.13	0
		B	0.472	0.432	0.142	0	13.6	12.4	4.08	0
		C	0.487	0.447	0.142	0	13.9	12.7	4.04	0
		D	0.492	0.457	0.145	0	13.8	12.8	4.06	0
		E	0.462	0.429	0.134	0	14.0	13.0	4.08	0
8	$P_0\ T_2\ H_1$	A	0.370	0.336	0.143	0	10.8	9.84	4.20	0
		B	0.339	0.309	0.140	0	10.0	9.14	4.13	0
		C	0.349	0.317	0.141	0	10.3	9.31	4.15	0
		D	0.357	0.334	0.152	0	10.3	9.60	4.39	0
		E	0.335	0.308	0.151	0	10.5	9.66	4.74	0
9	$P_0\ T_2\ H_2$	A	0.234	0.232	0.125	0.0005	7.05	7.01	3.71	0.02
		B	0.231	0.224	0.120	0	7.08	6.84	3.68	0
		C	0.257	0.242	0.132	0	7.78	7.34	3.99	0
		D	0.239	0.230	0.126	0	7.14	6.86	3.76	0
		E	0.230	0.214	0.116	0	7.43	6.93	3.76	0
10	$P_0\ T_3\ H_0$	A	0.724	0.706	0.092	0	23.8	23.2	3.01	0
		B	0.756	0.712	0.060	0	25.2	23.7	2.01	0
		C	0.795	0.758	0.048	0	26.2	25.0	1.57	0
		D	0.811	0.780	0.046	0	26.3	25.3	1.50	0
		E	0.754	0.703	0.047	0	26.6	24.8	1.67	0
11	$P_0\ T_3\ H_1$	A	0.525	0.504	0.073	0	17.8	17.1	2.49	0
		B	0.511	0.498	0.082	0	17.6	17.1	2.80	0
		C	0.526	0.511	0.070	0	17.9	17.4	2.37	0
		D	0.561	0.544	0.096	0	18.8	18.2	3.21	0
		E	0.524	0.506	0.095	0	19.0	18.4	3.47	0
12	$P_0\ T_3\ H_2$	A	0.329	0.308	0.084	0	11.5	10.8	2.96	0
		B	0.309	0.295	0.097	0	11.0	10.5	3.42	0
		C	0.317	0.310	0.094	0	11.2	10.9	3.32	0
		D	0.326	0.314	0.096	0	11.3	10.9	3.31	0
		E	0.318	0.303	0.098	0	11.9	11.4	3.65	0

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.
Combustor Pressure, P_0 = 7.5 atm.
Inlet Air Temperature, T_2 = 800 F, T_3 = 1000 F.
Inlet Air Humidity, H_0 = 0.2, H_1 = 2.2, H_2 = 4.2 lbs H_2O/lb dry air x 100.
(b) Calculated as NO_2.
(c) Calculated as Carbon.

TABLE 15 (Continued)

CALCULATED EMISSIONS WITH VARIATIONS IN FUELS AND OPERATING CONDITIONS (a)
(Program 1)

Test Cond. No.	Test Conds.	Test Fuel	Mass of Emissions, lbs/hr (b) NO_x	(b) NO	CO	(c) HC	Emission Index, lbs/1000-lbs fuel (b) NO_x	(b) NO	CO	(c) HC
13	P_1 T_0 H_0	A	0.453	0.377	0.410	0.0061	6.58	5.48	5.96	0.09
		B	0.399	0.311	0.404	0	5.86	4.57	5.93	0
		C	0.409	0.316	0.438	0	5.96	4.60	6.38	0
		D	0.412	0.352	0.497	0.0015	5.90	5.04	7.12	0.02
		E	0.404	0.321	0.352	0	6.28	4.99	5.46	0
14	P_1 T_0 H_1	A	0.253	0.223	0.579	0.0062	3.80	3.35	8.71	0.09
		B	0.268	0.215	0.600	0.0072	4.06	3.27	9.11	0.11
		C	0.248	0.208	0.622	0.0063	3.74	3.14	9.39	0.10
		D	0.277	0.244	0.643	0.0061	4.11	3.61	9.54	0.09
		E	0.255	0.200	0.548	0.0067	4.09	3.22	8.82	0.11
15	P_1 T_0 H_2	A	0.184	0.187	0.603	0.0086	2.84	2.89	9.30	0.13
		B	0.183	0.168	0.806	0.0177	2.85	2.62	12.6	0.28
		C	0.191	0.169	0.723	0.0088	2.96	2.62	11.2	0.14
		D	0.197	0.176	0.792	0.0098	3.01	2.68	12.1	0.15
		E	0.176	0.173	0.555	0.0069	2.91	2.85	9.16	0.11
16	P_1 T_1 H_0	A	0.470	0.448	0.330	0.0044	8.42	8.03	5.92	0.08
		B	0.450	0.378	0.303	0.0043	8.14	6.85	5.50	0.08
		C	0.492	0.446	0.281	0.0042	8.84	8.00	5.05	0.08
		D	0.476	0.476	0.355	0.0042	8.41	8.41	6.28	0.07
		E	0.454	0.409	0.225	0.0042	8.71	7.82	4.31	0.08
17	P_1 T_1 H_1	A	0.331	0.299	0.313	0.0046	6.12	5.52	5.78	0.08
		B	0.308	0.292	0.256	0.0040	5.75	5.46	4.79	0.07
		C	0.321	0.290	0.305	0.0040	5.96	5.39	5.66	0.08
		D	0.327	0.324	0.316	0.0041	4.11	5.92	5.76	0.08
		E	0.311	0.269	0.250	0.0041	4.09	5.32	4.95	0.08
18	P_1 T_1 H_2	A	0.225	0.204	0.266	0.0043	4.29	3.89	5.06	0.08
		B	0.215	0.182	0.269	0.0041	4.15	3.50	5.18	0.08
		C	0.227	0.220	0.272	0.0042	4.34	4.22	5.21	0.08
		D	0.236	0.234	0.299	0.0043	4.43	4.41	5.61	0.08
		E	0.214	0.203	0.225	0.0044	4.36	4.14	4.59	0.09

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.
Combustor Pressure, P_1 = 10.0 atm.
Inlet Air Temperature, T_0 = 400 F, T_1 = 600 F.
Inlet Air Humidity, H_0 = 0.2, H_1 = 2.2, H_2 = 4.2 lbs H_2O/lb dry air x 100.
(b) Calculated as NO_2.
(c) Calculated as Carbon.

TABLE 15 (Continued)

CALCULATED EMISSIONS WITH VARIATIONS IN FUELS AND OPERATING CONDITIONS (a)
(Program 1)

Test Cond. No.	Test Conds.	Test Fuel	Mass of Emissions, lbs/hr (b) NO_x	(b) NO	CO	(c) HC	Emission Index, lbs/1000-lbs fuel (b) NO_x	(b) NO	CO	(c) HC
19	$P_1\ T_2\ H_0$	A	0.638	0.647	0.114	0.0008	13.6	13.8	2.42	0.02
		B	0.720	0.685	0.120	0	15.5	14.7	2.59	0
		C	0.666	0.647	0.142	0	14.2	13.8	3.02	0
		D	0.683	0.676	0.125	0	14.3	14.2	2.63	0
		E	0.645	0.612	0.128	0	14.7	13.9	2.92	0
20	$P_1\ T_2\ H_1$	A	0.464	0.439	0.146	0	10.2	9.64	3.20	0
		B	0.466	0.451	0.153	0	10.4	10.0	3.39	0
		C	0.477	0.474	0.147	0	10.5	10.4	3.24	0
		D	0.499	0.494	0.153	0	10.8	10.7	3.32	0
		E	0.458	0.436	0.127	0	10.8	10.2	2.98	0
21	$P_1\ T_2\ H_2$	A	0.320	0.305	0.122	0	7.26	6.91	2.76	0
		B	0.298	0.296	0.118	0	7.22	7.16	2.85	0
		C	0.330	0.319	0.133	0	7.51	7.25	3.03	0
		D	0.308	0.314	0.130	0	6.90	7.03	2.91	0
		E	0.313	0.311	0.116	0	7.59	7.53	2.81	0
22	$P_1\ T_3\ H_0$	A	1.053	0.985	0.101	0.0036	25.9	24.3	2.49	0.09
		B	1.014	0.949	0.088	0.0036	25.3	23.7	2.18	0.09
		C	1.050	0.997	0.086	0.0033	26.0	24.7	2.13	0.08
		D	1.007	0.959	0.067	0.0029	24.5	23.3	1.64	0.07
		E	1.004	0.931	0.080	0.0034	26.5	24.6	2.12	0.09
23	$P_1\ T_3\ H_1$	A	0.727	0.689	0.084	0.0032	18.5	17.5	2.13	0.08
		B	0.711	0.678	0.075	0	18.3	17.5	1.93	0
		C	0.769	0.730	0.078	0.0022	19.6	18.6	2.00	0.06
		D	0.782	0.758	0.081	0	19.7	19.0	2.02	0
		E	0.696	0.664	0.076	0	19.0	18.1	2.08	0
24	$P_1\ T_3\ H_2$	A	0.523	0.482	0.067	0.0030	13.7	12.6	1.75	0.08
		B	0.509	0.476	0.069	0.0010	13.5	12.7	1.83	0.03
		C	0.516	0.498	0.069	0	13.6	13.1	1.81	0
		D	0.523	0.506	0.073	0.0009	13.6	13.1	1.88	0.02
		E	0.486	0.456	0.070	0	13.7	12.8	1.95	0

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.
Combustor Pressure, P_1 = 10.0 atm.
Inlet Air Temperature, T_2 = 800 F, T_3 = 1000 F
Inlet Air Humidity, H_0 = 0.2, H_1 = 2.2, H_2 = 4.2 lbs H_2O/lb dry air x 100.
(b) Calculated as NO_2.
(c) Calculated as Carbon.

TABLE 15 (Continued)

CALCULATED EMISSIONS WITH VARIATIONS IN FUEL AND OPERATING CONDITIONS (a)
(Program 1)

Test Cond. No.	Test Conds.	Test Fuel	Mass of Emissions, lbs/hr				Emission Index, lbs/1000-lbs fuel			
			(b) NO_x	(b) NO	CO	(c) HC	(b) NO_x	(b) NO	CO	(c) HC
25	$P_2\ T_0\ H_0$	A	0.516	0.445	0.915	0.0078	5.99	5.16	10.6	0.09
		B	0.511	0.417	0.528	0.0074	6.00	4.89	6.19	0.09
		C	0.523	0.469	0.771	0.0072	6.08	5.46	8.97	0.08
		D	0.551	0.483	0.533	0.0072	6.31	5.54	6.10	0.08
		E	0.501	0.408	0.417	0.0074	6.21	5.06	5.18	0.09
26	$P_2\ T_0\ H_1$	A	0.369	0.322	0.646	0.0070	4.42	3.86	7.75	0.08
		B	0.328	0.269	0.684	0	3.98	3.27	8.30	0
		C	0.345	0.308	0.668	0	4.16	3.70	8.03	0
		D	0.352	0.323	0.688	0	4.17	3.82	8.16	0
		E	0.322	0.273	0.546	0	4.13	3.51	7.00	0
27	$P_2\ T_0\ H_2$	A	0.245	0.239	0.739	0.0086	3.02	2.95	9.12	0.11
		B	0.247	0.238	0.804	0.0091	3.08	2.97	10.0	0.11
		C	0.287	0.248	0.856	0.0084	3.55	3.07	10.6	0.10
		D	0.267	0.236	0.847	0.0076	3.26	2.88	10.3	0.09
		E	0.244	0.223	0.656	0.0083	3.22	2.95	8.66	0.11
28	$P_2\ T_1\ H_0$	A	0.702	0.646	0.258	0.0060	10.0	9.23	3.69	0.09
		B	0.693	0.626	0.259	0.0057	10.0	9.04	3.75	0.08
		C	0.713	0.631	0.266	0.0056	10.2	9.05	3.81	0.08
		D	0.747	0.701	0.267	0.0060	10.5	9.89	3.77	0.08
		E	0.657	0.590	0.256	0.0007	10.0	9.02	3.92	0.01
29	$P_2\ T_1\ H_1$	A	0.467	0.416	0.434	0	6.89	6.14	6.41	0
		B	0.473	0.421	0.345	0	7.06	6.30	5.16	0
		C	0.499	0.457	0.478	0.0056	7.39	6.77	7.08	0.08
		D	0.510	0.479	0.448	0	7.44	6.99	6.53	0
		E	0.454	0.409	0.451	0	7.18	6.47	7.12	0
30	$P_2\ T_1\ H_2$	A	0.336	0.310	0.302	0	5.23	4.83	4.72	0
		B	0.317	0.288	0.341	0	5.00	4.54	5.37	0
		C	0.334	0.299	0.353	0	5.22	4.67	5.52	0
		D	0.330	0.318	0.368	0	5.08	4.89	5.66	0
		E	0.303	0.270	0.339	0	5.06	4.49	5.65	0

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.
Combustor Pressure, P_2 = 12.5 atm.
Inlet Air Temperature, T_0 = 400 F, T_1 = 600 F.
Inlet Air Humidity, H_0 = 0.2, H_1 = 2.2, H_2 = 4.2 lbs H_2O/lb dry air x 100.
(b) Calculated as NO_2.
(c) Calculated as Carbon.

TABLE 15 (Continued)

CALCULATED EMISSIONS WITH VARIATIONS IN FUELS AND OPERATING CONDITIONS (a)
(Program 1)

Test Cond. No.	Test Conds.	Test Fuel	Mass of Emissions, lbs/hr (b) NO_x	(b) NO	CO	(c) HC	Emission Index, lbs/1000-lbs fuel (b) NO_x	(b) NO	CO	(c) HC
31	P_2 T_2 H_0	A	0.934	0.841	0.134	0	15.8	14.3	2.26	0
		B	0.925	0.852	0.124	0	15.8	14.6	2.12	0
		C	0.933	0.882	0.144	0.0045	15.9	15.0	2.44	0.08
		D	0.958	0.917	0.154	0.0040	16.0	15.3	2.57	0.07
		E	0.882	0.820	0.127	0.0046	16.0	14.9	2.30	0.08
32	P_2 T_2 H_1	A	0.626	0.615	0.120	0	11.0	10.8	2.10	0
		B	0.573	0.564	0.147	0	10.2	10.0	2.61	0
		C	0.597	0.571	0.145	0	10.9	10.4	2.63	0
		D	0.609	0.596	0.154	0	10.6	10.3	2.66	0
		E	0.561	0.513	0.115	0	10.5	9.65	2.16	0
33	P_2 T_2 H_2	A	0.432	0.427	0.130	0	7.82	7.74	2.36	0
		B	0.411	0.396	0.140	0	7.54	7.24	2.56	0
		C	0.410	0.404	0.181	0	7.46	7.35	3.28	0
		D	0.451	0.454	0.180	0	8.06	8.12	3.23	0
		E	0.410	0.401	0.136	0	7.94	7.76	2.63	0
34	P_2 T_3 H_0	A	1.570	1.441	0.094	0.0005	31.0	28.4	1.86	0.01
		B	1.563	1.405	0.065	0	31.2	28.0	1.30	0
		C	1.621	1.540	0.072	0.0009	32.1	30.5	1.42	0.02
		D	1.628	1.606	0.086	0.0010	31.7	31.3	1.67	0.02
		E	1.443	1.359	0.062	0	30.4	28.7	1.30	0
35	P_2 T_3 H_1	A	0.989	0.933	0.086	0	20.1	19.0	1.75	0
		B	0.884	0.828	0.102	0	18.2	17.0	2.11	0
		C	0.946	0.900	0.095	0	19.3	18.4	1.93	0
		D	0.968	0.931	0.092	0	19.4	18.7	1.85	0
		E	0.939	0.861	0.105	0	20.4	18.8	2.29	0
36	P_2 T_3 H_2	A	0.695	0.633	0.091	0	14.6	13.9	1.92	0
		B	0.671	0.614	0.103	0	14.2	13.0	2.19	0
		C	0.704	0.680	0.088	0	14.8	14.3	1.86	0
		D	0.716	0.701	0.090	0	14.8	14.6	1.86	0
		E	0.643	0.599	0.089	0	14.4	13.5	2.00	0

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.
Combustor Pressure, P_2 = 12.5 atm.
Inlet Air Temperature, T_2 = 800 F, T_3 = 1000 F.
Inlet Air Humidity, H_0 = 0.2, H_1 = 2.2, H_2 = 4.2 lbs H_2O/lb dry air x 100.
(b) Calculated as NO_2.
(c) Calculated as Carbon.

TABLE 15 (Continued)

CALCULATED EMISSIONS WITH VARIATIONS IN FUELS AND OPERATING CONDITIONS (a)
(Program 1)

Test Cond. No.	Test Conds.	Test Fuel	Mass of Emissions, lbs/hr				Emission Index, lbs/1000-lbs fuel			
			(b) NO_x	(b) NO	CO	(c) HC	(b) NO_x	(b) NO	CO	(c) HC
37	$P_3\ T_0\ H_0$	A	0.687	0.719	0.909	0	6.67	6.98	8.82	0
		B	0.676	0.682	0.796	0	6.64	6.70	7.82	0
		C	0.725	0.738	0.806	0	7.06	7.19	7.84	0
		D	0.692	0.708	1.016	0	6.64	6.79	9.74	0
		E	0.710	0.719	0.649	0	7.37	7.47	6.74	0
38	$P_3\ T_0\ H_1$	A	0.498	0.492	1.191	0.0042	4.98	4.92	11.9	0.04
		B	0.500	0.497	0.936	0	5.05	5.02	9.45	0
		C	0.515	0.512	0.919	0	5.16	5.13	9.21	0
		D	0.504	0.510	1.118	0	4.97	5.04	11.0	0
		E	0.488	0.463	0.805	0	5.21	4.95	8.60	0
39	$P_3\ T_0\ H_2$	A	0.360	0.352	1.099	0.0141	3.71	3.62	11.3	0.14
		B	0.357	0.369	1.178	0.0140	3.71	3.84	12.3	0.15
		C	0.366	0.372	1.294	0.0142	3.77	3.84	13.4	0.15
		D	0.350	0.359	1.566	0.0158	3.56	3.65	15.9	0.15
		E	0.353	0.324	1.112	0.0133	3.88	3.56	12.2	0.15
40	$P_3\ T_1\ H_0$	A	0.753	0.845	0.445	0	8.98	10.1	5.30	0
		B	0.783	0.787	0.449	0	9.43	9.48	5.40	0
		C	0.852	0.767	0.514	0	10.2	9.17	6.15	0
		D	0.849	0.948	0.618	0	9.99	11.2	7.26	0
		E	0.744	0.768	0.407	0	9.88	9.80	5.19	0
41	$P_3\ T_1\ H_1$	A	0.570	0.596	0.665	0	7.04	7.36	8.21	0
		B	0.549	0.528	0.648	0	6.86	6.59	8.09	0
		C	0.530	0.541	0.655	0	6.56	6.70	8.10	0
		D	0.540	0.548	0.711	0	6.59	6.68	8.67	0
		E	0.523	0.532	0.552	0	6.92	7.03	7.29	0
42	$P_3\ T_1\ H_2$	A	0.380	0.386	0.757	0.0069	4.82	4.91	9.61	0.09
		B	0.344	0.353	0.717	0	4.42	4.54	9.21	0
		C	0.348	0.361	0.774	0	4.43	4.60	9.86	0
		D	0.364	0.382	0.824	0	4.57	4.79	10.3	0
		E	0.347	0.351	0.668	0.0068	4.71	4.77	9.08	0.09

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.
Combustor Pressure, P_3 = 15.0 atm.
Inlet Air Temperature, T_0 = 400 F, T_1 = 600 F.
Inlet Air Humidity, H_0 = 0.2, H_1 = 2.2, H_2 = 4.2 lbs H_2O/lb dry air x 100.
(b) Calculated as NO_2.
(c) Calculated as Carbon.

TABLE 15 (Continued)

CALCULATED EMISSIONS WITH VARIATIONS IN FUELS AND OPERATING CONDITIONS (a)
(Program 1)

Test Cond. No.	Test Conds.	Test Fuel	Mass of Emissions, lbs/hr (b) NO_x	(b) NO	CO	(c) HC	Emission Index, lbs/1000-lbs fuel (b) NO_x	(b) NO	CO	(c) HC
43	$P_3\ T_2\ H_0$	A	1.134	1.091	0.394	0	16.1	15.5	5.59	0
		B	1.170	1.107	0.318	0	16.8	15.8	4.55	0
		C	1.157	1.103	0.372	0	16.4	15.7	5.28	0
		D	1.222	1.162	0.378	0	17.1	16.3	5.29	0
		E	1.135	1.018	0.352	0	17.2	15.4	5.34	0
44	$P_3\ T_2\ H_1$	A	0.782	0.834	0.200	0	11.4	12.2	2.94	0
		B	0.830	0.802	0.232	0	12.3	11.9	3.43	0
		C	0.833	0.832	0.227	0	12.2	12.2	3.33	0
		D	0.845	0.835	0.212	0	12.2	12.1	3.06	0
		E	0.722	0.708	0.218	0	11.3	11.1	3.41	0
45	$P_3\ T_2\ H_2$	A	0.568	0.565	0.238	0	8.63	8.57	4.21	0
		B	0.554	0.525	0.336	0	8.50	8.05	5.16	0
		C	0.587	0.570	0.312	0	8.92	8.66	4.74	0
		D	0.587	0.574	0.309	0	8.79	8.59	4.62	0
		E	0.522	0.494	0.342	0	8.46	8.01	5.54	0
46	$P_3\ T_3\ H_0$	A	1.770	1.728	0.078	0	29.2	28.5	1.29	0
		B	1.718	1.602	0.080	0	28.6	26.7	1.33	0
		C	1.830	1.727	0.077	0.0045	30.2	28.5	1.27	0.07
		D	1.987	1.863	0.089	0.0011	32.3	30.3	1.44	0.02
		E	1.836	1.704	0.089	0	32.3	30.0	1.57	0
47	$P_3\ T_3\ H_1$	A	1.361	1.268	0.127	0	23.1	21.5	2.16	0
		B	1.238	1.136	0.146	0	21.2	19.5	2.50	0
		C	1.298	1.222	0.134	0	22.1	20.8	2.26	0
		D	1.338	1.316	0.153	0	22.4	22.0	2.57	0
		E	1.202	1.124	0.138	0	21.8	20.4	2.49	0
48	$P_3\ T_3\ H_2$	A	0.924	0.885	0.095	0.0011	16.2	15.5	1.66	0.02
		B	0.890	0.828	0.107	0.0047	15.8	14.7	1.88	0.08
		C	0.899	0.865	0.104	0.0045	15.8	15.2	1.83	0.08
		D	0.910	0.913	0.109	0.0023	15.7	15.8	1.88	0.04
		E	0.851	0.815	0.099	0.0027	15.9	15.3	1.85	0.05

(a) Reference Velocity = 140 ft/sec.
Heat Input = 300 Btu/lb air.
Combustor Pressure, P_3 = 15.0 atm.
Inlet Air Temperature, T_2 = 800 F, T_3 = 1000 F.
Inlet Air Humidity, H_0 = 0.2, H_1 = 2.2, H_2 = 4.2 lbs H_2O/lb dry air x 100.
(b) Calculated as NO_2.
(c) Calculated as Carbon.

TABLE 16

CALCULATED EMISSIONS WITH VARIATIONS IN FUELS AND OPERATING CONDITIONS (a)
(Prevaporized Fuels)

Test Cond. No.	Test Conds.	Test Fuel	Mass of Emissions, lbs/hr				Emission Index, lbs/1000-lbs fuel			
			(b) NO_x	(b) NO	CO	(c) HC	(b) NO_x	(b) NO	CO	(c) HC
49	$P_1T_1F_1H_0$	A	0.341	0.314	0.128	0	12.2	11.3	4.61	0
		B	0.334	0.308	0.136	0	12.1	11.1	4.9	0
		C	0.340	0.319	0.131	0	12.2	11.5	4.7	0
		D	0.355	0.333	0.133	0	12.6	11.8	4.7	0
		E	0.316	0.292	0.127	0	11.5	10.6	4.6	0
53	$P_1T_1F_1H_1$	A	0.221	0.215	0.208	0.0049	8.18	7.95	7.72	0.18
		B	0.222	0.220	0.251	0.0083	8.26	8.22	9.38	0.31
		C	0.228	0.217	0.221	0.0042	8.46	8.04	8.18	0.16
		D	0.233	0.223	0.222	0.0038	8.50	8.14	8.08	0.14
		E	0.212	0.196	0.224	0.0068	7.97	7.36	8.40	0.26
57	$P_1T_1F_1H_2$	A	0.146	0.137	0.335	0	5.57	5.24	12.8	0
		B	0.143	0.142	0.360	0.0049	5.50	5.46	13.8	0.19
		C	0.146	0.138	0.366	0	5.57	5.29	14.0	0
		D	0.151	0.147	0.388	0.0019	5.67	5.53	14.6	0.07
		E	0.137	0.128	0.361	0.0041	5.30	4.97	14.0	0.16
50	$P_1T_2F_1H_0$	A	0.483	0.450	0.117	0	20.6	19.2	4.97	0
		B	0.482	0.458	0.114	0	20.8	19.7	4.90	0
		C	0.494	0.460	0.112	0	21.1	19.7	4.81	0
		D	0.525	0.494	0.110	0	22.0	20.7	4.64	0
		E	0.466	0.438	0.110	0	20.2	18.9	4.78	0
54	$P_1T_2F_1H_1$	A	0.277	0.262	0.138	0	12.2	11.5	6.03	0
		B	0.281	0.261	0.129	0	12.5	11.6	5.74	0
		C	0.288	0.272	0.127	0	12.7	12.0	5.58	0
		D	0.313	0.289	0.129	0	13.6	12.5	5.57	0
		E	0.263	0.243	0.128	0	11.8	10.9	5.70	0
58	$P_1T_2F_1H_2$	A	0.189	0.182	0.222	0	8.52	8.20	9.99	0
		B	0.194	0.177	0.256	0	8.92	8.11	11.8	0
		C	0.194	0.181	0.228	0	8.80	8.23	10.3	0
		D	0.197	0.182	0.241	0	8.80	8.12	10.8	0
		E	0.176	0.166	0.232	0	8.09	7.63	10.7	0

(a) Reference Velocity = 140 ft/sec.
Combustor Pressure, P_1 = 10.0 atm.
Inlet Air Temperature, T_1 = 600 F, T_2 = 800 F.
Heat Input, F_1 = 150 Btu/lb air.
Inlet Air Humidity, H_0 = 0.2, H_1 = 2.2, H_2 = 4.2 lbs H_2O/lb dry air x 100.
(b) Calculated as NO_2.
(c) Calculated as carbon.

TABLE 16 (Continued)

CALCULATED EMISSIONS WITH VARIATIONS IN FUELS AND OPERATING CONDITIONS (a)
(Prevaporized Fuels)

Test Cond. No.	Test Conds.	Test Fuel	Mass of Emissions, lbs/hr (b) NO_x	(b) NO	CO	(c) HC	Emission Index, lbs/1000-lbs fuel (b) NO_x	(b) NO	CO	(c) HC
51	$P_2T_1F_1H_0$	A	0.448	0.429	0.114	0	12.8	12.2	3.26	0
		B	0.470	0.451	0.124	0	13.6	13.0	3.58	0
		C	0.482	0.451	0.112	0	13.8	12.9	3.21	0
		D	0.474	0.458	0.126	0	13.4	12.9	3.57	0
		E	0.405	0.380	0.141	0	11.8	11.0	4.09	0
55	$P_2T_1F_1H_1$	A	0.276	0.253	0.302	0.0065	8.18	7.49	8.93	0.19
		B	0.264	0.253	0.317	0.0036	7.87	7.55	9.45	0.11
		C	0.253	0.264	0.336	0.0052	7.49	7.80	9.93	0.16
		D	0.298	0.289	0.284	0	8.70	8.44	8.28	0
		E	0.249	0.231	0.350	0	7.47	6.94	10.5	0
59	$P_2T_1F_1H_2$	A	0.202	0.193	0.452	0	6.16	5.89	13.8	0
		B	0.183	0.183	0.542	0.0024	5.67	5.67	16.8	0.07
		C	0.201	0.160	0.650	0.0106	6.16	4.91	19.9	0.33
		D	0.210	0.205	0.473	0	6.35	6.19	14.3	0
		E	0.159	0.147	0.730	0.0224	4.94	4.56	22.7	0.70
52	$P_2T_2F_1H_0$	A	0.650	0.633	0.137	0	22.0	21.5	4.64	0
		B	0.629	0.608	0.133	0	21.5	20.8	4.55	0
		C	0.672	0.674	0.134	0	22.9	22.9	4.56	0
		D	0.678	0.657	0.130	0	22.7	22.0	4.34	0
		E	0.627	0.592	0.127	0	21.6	20.4	4.39	0
56	$P_2T_2F_1H_1$	A	0.383	0.360	0.170	0	13.4	12.6	5.95	0
		B	0.362	0.349	0.166	0	12.8	12.4	5.88	0
		C	0.381	0.357	0.163	0	13.4	12.6	5.75	0
		D	0.398	0.367	0.158	0	13.8	12.7	5.50	0
		E	0.357	0.336	0.158	0	12.7	12.0	5.63	0
60	$P_2T_2F_1H_2$	A	0.259	0.240	0.256	0	9.40	8.69	9.29	0
		B	0.238	0.221	0.269	0	8.71	8.08	9.84	0
		C	0.249	0.247	0.259	0	9.04	8.99	9.42	0
		D	0.280	0.261	0.254	0	9.99	9.31	9.07	0
		E	0.240	0.222	0.263	0	8.81	8.15	9.67	0

(a) Reference Velocity = 140 ft/sec.
Combustor Pressure, P_2 = 12.5 atm.
Inlet Air Temperature, T_1 = 600 F, T_2 = 800 F.
Heat Input, F_1 = 150 Btu/lb air.
Inlet Air Humidity, H_0 = 0.2, H_1 = 2.2, H_2 = 4.2 lbs H_2O/lb dry air x 100.
(b) Calculated as NO_2.
(c) Calculated as carbon.

TABLE 16 (Continued)

CALCULATED EMISSIONS WITH VARIATIONS IN FUELS AND OPERATING CONDITIONS (a)
(Prevaporized Fuels)

Test Cond. No.	Test Conds.	Test Fuel	Mass of Emissions, lbs/hr (b) NO_x	(b) NO	CO	(c) HC	Emission Index, lbs/1000-lbs fuel (b) NO_x	(b) NO	CO	(c) HC
61	$P_4T_4F_2H_1$	A	0.346	0.335	0.250	0	8.29	8.04	5.98	0
		B	0.333	0.319	0.272	0	8.07	7.71	6.58	0
		C	0.329	0.306	0.337	0	7.91	7.36	8.10	0
		D	0.364	0.362	0.246	0	8.61	8.55	5.81	0
		E	0.345	0.330	0.267	0	8.40	8.04	6.50	0
66	$P_0T_4F_2H_1$	A	0.201	0.182	0.143	0	7.23	6.56	5.15	0
		B	0.193	0.180	0.138	0	7.03	6.53	5.00	0
		C	0.199	0.190	0.156	0	7.19	6.84	5.63	0
		D	0.208	0.192	0.151	0	7.38	6.82	5.34	0
		E	0.199	0.185	0.155	0	7.27	6.74	5.67	0
67	$P_3T_4F_2H_1$	A	0.696	0.556	0.552	0	12.5	10.0	9.94	0
		B	0.523	0.531	0.538	0	9.52	9.67	9.79	0
		C	0.535	0.531	0.475	0	9.66	9.58	8.57	0
		D	0.569	0.577	0.493	0	10.1	10.2	8.76	0
		E	0.492	0.494	0.482	0	8.99	9.03	8.81	0
68	$P_4T_0F_2H_1$	A	0.276	0.261	0.631	0	4.88	4.63	11.2	0
		B	0.263	0.253	0.614	0	4.71	4.53	11.0	0
		C	0.257	0.259	0.968	0.0312	4.57	4.61	17.2	0.56
		D	0.291	0.298	0.653	0	5.10	5.21	11.4	0
		E	0.272	0.245	0.753	0.0082	4.89	4.41	13.6	0.15
69	$P_4T_3F_2H_1$	A	0.579	0.561	0.186	0	17.5	16.9	5.63	0
		B	0.559	0.539	0.210	0	17.0	16.4	6.41	0
		C	0.588	0.542	0.204	0	17.8	16.4	6.16	0
		D	0.580	0.582	0.186	0	17.3	17.3	5.53	0
		E	0.538	0.521	0.182	0	16.5	16.0	5.58	0
64	$P_4T_4F_2H_0$	A	0.539	0.509	0.159	0	12.8	11.8	3.57	0
		B	0.519	0.489	0.154	0	12.2	11.5	3.62	0
		C	0.578	0.522	0.146	0	13.5	12.2	3.40	0
		D	0.571	0.548	0.153	0	13.1	12.6	3.50	0
		E	0.539	0.512	0.152	0	12.7	12.0	3.58	0

(a) Reference Velocity = 140 ft/sec.
Combustor Pressure, P_0 = 7.5, P_3 = 15.0, P_4 = 11 25 atm.
Inlet Air Temperature, T_0 = 400 F, T_3 = 1000 F, T_4 = 700 F.
Heat Input, F_2 = 225 Btu/lb air.
Inlet Air Humidity, H_0 = 0.2, H_1 = 2.2 lbs H_2O/lb dry air x 100.
(b) Calculated as NO_2.
(c) Calculated as carbon.

TABLE 16 (Continued)

CALCULATED EMISSIONS WITH VARIATIONS IN FUELS AND OPERATING CONDITIONS (a)
(Prevaporized Fuels)

Test Cond. No.	Test Conds.	Test Fuel	Mass of Emissions, lbs/hr (b) NO_x	(b) NO	CO	(c) HC	Emission Index, lbs/1000-lbs fuel (b) NO_x	(b) NO	CO	(c) HC
65	$P_4T_4F_2H_2$	A	0.240	0.240	0.581	0	5.92	5.92	14.3	0
		B	0.243	0.225	0.583	0	6.07	5.63	14.6	0
		C	0.225	0.196	0.730	0.0057	5.57	4.86	18.1	0.14
		D	0.238	0.222	0.654	0	5.80	5.41	15.9	0
		E	0.238	0.225	0.575	0	5.99	5.66	14.4	0
63	$P_4T_4F_0H_1$	A	0.298	0.285	0.350	0	16.0	15.3	18.8	0
		B	0.292	0.281	0.235	0	16.0	15.3	12.8	0
		C	0.288	0.278	0.231	0	15.5	15.0	12.5	0
		D	0.296	0.287	0.236	0	15.7	15.3	12.6	0
		E	0.272	0.267	0.248	0	14.9	14.6	13.5	0
62	$P_4T_4F_3H_1$	A	0.630	0.635	0.404	0	9.71	9.78	6.22	0
		B	0.640	0.592	0.388	0	9.97	9.23	6.06	0
		C	0.597	0.593	0.479	0	9.71	9.14	7.39	0
		D	0.631	0.621	0.487	0	9.59	9.44	7.40	0
		E	0.628	0.584	0.429	0	9.82	9.14	6.72	0

(a) Reference Velocity = 140 ft/sec.
Combustor Pressure, P_4 = 11.25 atm.
Inlet Air Temperature, T_4 = 700 F.
Heat Input, F_0 = 100, F_2 = 225, F_3 = 350 Btu/lb air.
Inlet Air Humidity, H_1 = 2.2, H_2 = 4.2 lbs H_2O/lb dry air x 100.
(b) Calculated as NO_2.
(c) Calculated as carbon.

TABLE 17

CALCULATED EMISSIONS WITH VARIATIONS IN FUELS AND OPERATING CONDITIONS (a)
(Pressure Atomized Fuel)

Test Cond. No.	Test Conds.	Test Fuel	Mass of Emissions, lbs/hr (b) NO_x	(b) NO	CO	(c) HC	Emission Index, lbs/1000-lbs fuel (b) NO_x	(b) NO	CO	(c) HC
49	$P_1T_1F_1H_0$	A	0.297	0.286	0.071	0	10.6	10.2	2.55	0
		B	0.271	0.257	0.069	0	9.82	9.32	2.50	0
		C	0.293	0.277	0.070	0	10.5	9.98	2.52	0
		D	0.319	0.300	0.067	0	11.2	10.6	2.38	0
		E	0.276	0.259	0.070	0	10.0	9.41	2.53	0
53	$P_1T_1F_1H_1$	A	0.179	0.173	0.127	0	6.64	6.41	4.71	0
		B	0.174	0.164	0.130	0	6.49	6.14	4.85	0
		C	0.187	0.180	0.123	0	6.94	6.65	4.54	0
		D	0.198	0.187	0.123	0	7.21	6.82	4.50	0
		E	0.173	0.166	0.126	0	6.52	6.23	4.74	0
57	$P_1T_1F_1H_2$	A	0.123	0.117	0.195	0	4.71	4.48	7.43	0
		B	0.114	0.109	0.205	0	4.39	4.19	7.90	0
		C	0.118	0.111	0.223	0	4.50	4.25	8.50	0
		D	0.126	0.119	0.227	0	4.72	4.47	8.53	0
		E	0.111	0.101	0.212	0	4.32	3.92	8.21	0
50	$P_1T_2F_1H_0$	A	0.459	0.445	0.048	0	19.5	18.9	2.02	0
		B	0.440	0.419	0.060	0	19.0	18.1	2.59	0
		C	0.444	0.429	0.056	0	19.0	18.3	2.41	0
		D	0.494	0.480	0.059	0	20.8	20.2	2.49	0
		E	0.425	0.408	0.060	0	18.4	17.7	2.61	0
54	$P_1T_2F_1H_1$	A	0.316	0.300	0.081	0	13.8	13.2	3.54	0
		B	0.285	0.276	0.092	0	12.7	12.2	4.07	0
		C	0.298	0.281	0.094	0	13.1	12.4	4.12	0
		D	0.327	0.311	0.089	0	14.2	13.5	3.87	0
		E	0.276	0.266	0.085	0	12.3	11.9	3.81	0
58	$P_1T_2F_1H_2$	A	0.192	0.181	0.160	0	8.67	8.20	7.27	0
		B	0.172	0.165	0.181	0	7.88	7.56	8.31	0
		C	0.184	0.174	0.190	0	8.37	7.90	8.64	0
		D	0.197	0.174	0.193	0	8.80	7.75	8.61	0
		E	0.170	0.156	0.186	0	7.83	7.21	8.59	0

(a) Reference Velocity = 140 ft/sec.
Combustor Pressure, P_1 = 10.0 atm.
Inlet Air Temperature, T_1 = 600F, T_2 = 800F
Heat Input, F_1 = 150 Btu/lb air.
Inlet Air Humidity, H_0 = 0.2, H_1 = 2.2, H_2 = 4.2 lbs H_2O/lb dry air x 100.
(b) Calculated as NO_2.
(c) Calculated as carbon.

TABLE 17 (Continued)

CALCULATED EMISSIONS WITH VARIATIONS IN FUELS AND OPERATING CONDITIONS (a)
(Pressure Atomized Fuel)

Test Cond. No.	Test Conds.	Test Fuel	Mass of Emissions, lbs/hr (b) NO_x	(b) NO	CO	(c) HC	Emission Index, lbs/1000-lbs fuel (b) NO_x	(b) NO	CO	(c) HC
51	$P_2T_1F_1H_0$	A	0.393	0.373	0.114	0	11.2	10.6	3.24	0
		B	0.380	0.355	0.110	0	11.0	10.3	3.18	0
		C	0.387	0.369	0.108	0	11.1	10.6	3.10	0
		D	0.411	0.389	0.111	0	11.6	11.0	3.13	0
		E	0.366	0.339	0.114	0	10.6	9.85	3.33	0
55	$P_2T_1F_1H_1$	A	0.235	0.231	0.162	0	6.95	6.84	4.79	0
		B	0.217	0.214	0.160	0	6.49	6.38	4.78	0
		C	0.230	0.224	0.154	0	6.80	6.64	4.56	0
		D	0.232	0.237	0.155	0	6.75	6.91	4.53	0
		E	0.213	0.210	0.152	0	6.40	6.30	4.57	0
59	$P_2T_1F_1H_2$	A	0.162	0.170	0.225	0	4.97	5.19	6.88	0
		B	0.153	0.149	0.241	0	4.74	4.63	7.45	0
		C	0.154	0.149	0.237	0	4.73	4.57	7.27	0
		D	0.168	0.165	0.237	0	5.09	4.98	7.16	0
		E	0.148	0.143	0.231	0	4.61	4.45	7.16	0
52	$P_2T_2F_1H_0$	A	0.595	0.588	0.068	0	20.2	19.9	2.32	0
		B	0.567	0.553	0.073	0	19.4	18.9	2.52	0
		C	0.610	0.583	0.077	0	20.8	19.8	2.63	0
		D	0.612	0.590	0.073	0	20.5	19.7	2.45	0
		E	0.569	0.540	0.075	0	19.6	18.6	2.58	0
56	$P_2T_2F_1H_1$	A	0.397	0.389	0.140	0	13.9	13.6	4.92	0
		B	0.349	0.337	0.135	0	12.4	12.0	4.79	0
		C	0.364	0.361	0.120	0	12.8	12.7	4.23	0
		D	0.385	0.377	0.117	0	13.4	13.1	4.05	0
		E	0.336	0.336	0.136	0	12.0	12.0	4.85	0
60	$P_2T_2F_1H_2$	A	0.235	0.228	0.217	0	8.50	8.27	7.87	0
		B	0.227	0.222	0.252	0	8.31	8.13	9.22	0
		C	0.236	0.239	0.239	0	8.58	8.70	8.71	0
		D	0.259	0.254	0.260	0	9.24	9.06	9.27	0
		E	0.258	0.253	0.265	0	9.48	9.32	9.76	0

(a) Reference Velocity = 140 ft/sec.
Combustor Pressure, P_2 = 12.5 atm/
Inlet Air Temperature, T_1 = 600 F; T_2 = 800 F.
Heat Input, F_1 = 150 Btu/lb air.
Inlet Air Humidity, H_0 = 0.2, H_1 = 2.2, H_2 = 4.2 lbs H_2O/lb dry air x 100.
(b) Calculated as NO_2.
(c) Calculated as carbon.

TABLE 17 (Continued)

CALCULATED EMISSIONS WITH VARIATIONS IN FUELS AND OPERATING CONDITIONS (a)
(Pressure Atomized Fuel)

Test Cond. No.	Test Conds.	Test Fuel	Mass of Emissions, lbs/hr (b) NO_x	(b) NO	CO	(c) HC	Emission Index, lbs/1000-lbs fuel (b) NO_x	(b) NO	CO	(c) HC
61	$P_4T_4F_2H_1$	A	0.315	0.293	0.187	0	7.55	7.03	4.48	0
		B	0.324	0.297	0.193	0	7.84	7.19	4.67	0
		C	0.329	0.310	0.190	0	7.90	7.45	4.58	0
		D	0.350	0.324	0.203	0	8.28	7.66	4.81	0
		E	0.322	0.300	0.208	0	7.82	7.31	5.56	0
66	$P_0T_4F_2H_1$	A	0.191	0.172	0.115	0	6.86	6.18	4.13	0
		B	0.176	0.168	0.116	0	6.40	6.13	4.22	0
		C	0.192	0.170	0.112	0	6.95	6.14	4.04	0
		D	0.201	0.178	0.108	0	7.14	6.31	3.82	0
		E	0.180	0.160	0.115	0	6.57	5.84	4.21	0
67	$P_3T_4F_2H_1$	A	0.449	0.451	0.229	0	8.10	8.13	4.05	0
		B	0.423	0.413	0.256	0	7.70	7.53	4.67	0
		C	0.453	0.442	0.239	0	8.18	7.98	4.32	0
		D	0.465	0.455	0.244	0	8.25	8.09	4.34	0
		E	0.431	0.434	0.232	0	7.88	7.94	4.34	0
68	$P_4T_0F_2H_1$	A	0.226	0.194	0.439	0	4.01	3.43	7.79	0
		B	0.199	0.187	0.421	0	3.56	3.36	7.55	0
		C	0.218	0.213	0.468	0	3.88	3.79	8.32	0
		D	0.226	0.211	0.464	0	3.96	3.70	8.12	0
		E	0.223	0.193	0.416	0	4.01	3.47	7.49	0
69	$P_4T_3F_2H_1$	A	0.484	0.521	0.114	0	14.6	15.7	3.43	0
		B	0.482	0.460	0.128	0	14.7	14.0	3.90	0
		C	0.522	0.500	0.127	0	15.8	15.1	3.85	0
		D	0.524	0.506	0.117	0	15.6	15.1	3.49	0
		E	0.463	0.488	0.114	0	14.2	15.0	3.51	0
64	$P_4T_4F_2H_0$	A	0.521	0.490	0.150	0	12.1	11.4	3.49	0
		B	0.504	0.466	0.136	0	11.8	10.9	3.19	0
		C	0.524	0.488	0.131	0	12.2	11.4	3.06	0
		D	0.525	0.500	0.143	0	12.0	11.5	3.27	0
		E	0.511	0.475	0.141	0	12.1	11.2	3.32	0

(a) Reference Velocity = 140 ft/sec.
Combustor Pressure, P_0 = 7.5, P_3 = 15.0, P_4 = 11.25 atm.
Inlet Air Temperature, T_0 = 400F, T_3 = 1000 F, T_4 = 700 F.
Heat Input, F_2 = 225 Btu/lb air.
Inlet Air Humidity, H_0 = 0.2, H_1 = 2.2 lbs H_2O/lb dry air x 100.

(b) Calculated as NO_2.

(c) Calculated as carbon.

TABLE 17 (Continued)

CALCULATED EMISSIONS WITH VARIATIONS IN FUELS AND OPERATING CONDITIONS (a)
(Pressure Atomized Fuel)

Test Cond. No.	Test Conds.	Test Fuel	Mass of Emissions, lbs/hr (b) NO_x	(b) NO	CO	(c) HC	Emission Index, lbs/1000-lbs fuel (b) NO_x	(b) NO	CO	(c) HC
65	$P_4T_4F_2H_2$	A	0.231	0.222	0.308	0	5.70	5.48	7.62	0
		B	0.226	0.210	0.322	0	5.65	5.25	8.04	0
		C	0.230	0.214	0.343	0	5.68	5.29	8.48	0
		D	0.236	0.226	0.348	0	5.76	5.51	8.50	0
		E	0.217	0.204	0.333	0	5.45	5.13	8.38	0
63	$P_4T_4F_0H_1$	A	0.200	0.194	0.135	0	10.8	10.4	7.26	0
		B	0.197	0.186	0.128	0	10.7	10.1	7.00	0
		C	0.209	0.202	0.117	0	11.3	10.9	6.33	0
		D	0.205	0.196	0.128	0	10.9	10.4	6.82	0
		E	0.202	0.201	0.118	0	11.1	11.0	6.45	0
62	$P_4T_4F_3H_1$	A	0.470	0.434	0.313	0	7.24	6.69	4.82	0
		B	0.449	0.421	0.351	0	7.00	6.56	5.47	0
		C	0.457	0.437	0.360	0	7.05	6.74	5.55	0
		D	0.474	0.459	0.356	0	7.21	6.98	5.41	0
		E	0.456	0.416	0.290	0	7.14	6.51	4.54	0

(a) Reference Velocity = 140 ft/sec.
Combustor Pressure, P_4 = 11.25 atm.
Inlet Air Temperature, T_4 = 700 F.
Heat Input, F_0 = 100, F_2 = 225, F_3 = 350 Btu/lb air.
Inlet Air Humidity, H_1 = 2.2, H_2 = 4.2 lbs H_2O/lb dry air x 100.

(b) Calculated as NO_2.

(c) Calculated as carbon.

9. APPENDIX 3

(Statistical Analyses of Data)

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(Statistical Analyses of Data)

The objectives of this experimental investigation were to determine the effects which differences in JP fuels and operating variables have on flame radiance and exhaust emissions of nitrogen oxides, carbon monoxide, unburned hydrocarbons, and soot. Five kerosene-type fuels were selected to span the allowable range in molecular structure: including normal paraffins, isoparaffins, cycloparaffins and aromatics. Prevaporization and pressure atomization of fuels introduced to the combustor were included to minimize and maximize differences in physical properties of the fuels. Inlet air humidity was included as an operating variable in the investigation.

The experimental investigation was divided into two segments. Program 1 was an extension of the study conducted in the previous investigation (8) at four levels of combustor pressure, four levels of inlet-air temperature, three levels of inlet-air humidity and single levels of heat input rate and reference velocity. The current study was conducted with pressure atomized rather than prevaporized fuels. The remainder of the investigation consisted of a 21 point program with both prevaporized and pressure atomized fuels to evaluate the effect of heat input rate as an operating variable on flame radiance and exhaust emissions.

Detailed data obtained during the current investigation are presented in Appendix 2 (Section 8.). The data obtained with prevaporized fuels at the 48 combinations of operating conditions used in Program 1 are presented in Tables 16, 17, and 19 of Reference 8 and have been combined with the data obtained during the current investigation to evaluate the effect of the method of introduction of fuel into the combustor. Analyses of Variance of data for flame radiance, smoke emissions, NO_x, NO, and CO emissions for various combinations of operating variables were made. Values for unburned hydrocarbons were either zero or very low for most of the test points and detailed analyses of the data were not made. Empirical equations were developed for each response on the basis of statistically significant effects and interactions to use in the evaluation of the data obtained.

Two equations were developed for each response with one set of equations based on data from Program 1 and the other set of equations based on a small program to evaluate the effect of heat input rate. Program 1 consisted of a 4 x 4 x 3 x 2 experiment with four levels of combustor pressure from 7.5 to 15.0 atmospheres, four levels of inlet air temperature from 400 to 1000 F, three levels of inlet air humidity from 0.002 to 0.042 pounds of water per pound of dry air and two methods of introduction of fuel to the combustor (pressure atomized and prevaporized). Equations for the small program were based on a 2 x 2 x 2 x 2 x 3 experiment with two levels of combustor pressure of 10.0 and 12.5 atmospheres, two levels of inlet air temperature of 600 and 800 F, three levels of inlet air humidity of 0.002, 0.022 and 0.042, two methods of introduction of fuel to the combustor (pressure atomized and prevaporized) and two levels of heat input were obtained to provide a balanced experiment by combining data at a heat input rate of 150 Btu per pound of air in the small program with data at a heat input rate of 300 Btu per pound of air in Program 1. Program 1 with the wider range and multiple levels of variables provides better estimates (at fixed heat input) of the responses

covered than the equations developed for the small program. While the equations from the smaller program provide a measure of the effect of heat input rates over a narrow range of the other operating variables the interactions with heat input rate complicate the relationships. The estimated equations are presented in Tables 18 to 27. Values of the responses for each equation were calculated at the extremes of the ranges of the operating variables for the empirical equations to provide comparisons of the effects of fuels on flame radiance and exhaust emissions over a wide range of operating conditions. The calculated values are presented graphically in Figures 13 to 61 to provide comparisons of the effects of fuels and operating variables on flame radiance and exhaust emissions.

9.1. Fuel Effects

In all graphical comparisons of the effects of fuels on flame radiance and exhaust emissions the fuels have been listed in the order of increasing fuel hydrogen content. As shown in Table 3 hydrogen content of the fuels vary from 13.8 per cent for Fuel D to 15.5 for Fuel E.

The effects of differences among the five fuels on total radiant energy are shown in Figures 13, 14, and 15. The magnitude of the calculated total radiant energy varies with the levels of combustor pressure, inlet air temperature and inlet air humidity; however, the trend is for a decrease in flame radiance with an increase in fuel hydrogen content. In the small program total radiant energy with prevaporized fuel at the low heat input level was very low and either did not change with fuel hydrogen content or increased slightly. With pressure atomized fuel at the low heat input level total radiant energy decreased with fuel hydrogen content. At an inlet air temperature of 800 F and high inlet air humidity the change in total radiant energy with fuel hydrogen content was small.

The effects of fuels on smoke emissions are shown in Figures 16 and 17. At high levels of heat input and low inlet air temperatures smoke emissions decreased with an increase in hydrogen content of the fuels. At either low levels of heat input or high levels of inlet air temperature the level of smoke emissions is below the threshold of visible smoke (0.200) and fuels have little effect on the level of smoke emissions.

The relationships between fuels and NO_x and NO emissions are shown in Figures 18 to 23. At the high level of heat input in Program 1 the small differences in emissions are probably not of practical significance. With the low level of heat input and 800 F inlet air temperature and low inlet air humidity an increase in fuel hydrogen content reduces emissions slightly.

The effects of fuels on CO emissions are shown in Figures 24, 25, and 26. With a heat input rate of 300 Btu per pound of air and an inlet air temperature of 400 F CO emissions decrease with an increase in fuel hydrogen content and fuels have no appreciable effect on CO emissions at higher inlet air temperatures.

9.2. Effect of Method of Fuel Introduction to Combustor

Differences in total radiant energy with the introduction of fuel to the combustor by prevaporization and pressure atomization are shown in Figures

27, 28, and 29. In Program 1 with a heat input rate of 300 Btu per pound of air total radiant energy was greater with pressure atomized fuels than with prevaporized fuels with an inlet air temperature of 1000 F and was less with an inlet air temperature of 400 F. With a high heat input rate and low inlet air temperature combustion of the fuel may have been delayed and the point of maximum total radiant energy may have moved down stream from the point of observation. With a heat input rate of 150 Btu per pound of air total radiant energy was greater with pressure atomized fuel than with prevaporized fuel at all of the combinations of operating conditions evaluated.

Comparisons of the effects of prevaporized and pressure atomized fuels on smoke emissions are shown in Figures 30 and 31. At 300 Btu per pound of air heat input rate smoke optical density was greater with pressure atomized fuel than with prevaporized fuel at the high pressure-low temperature conditions. Smoke optical density was also greater with pressure atomized fuel for Fuel D at the low temperature-low pressure condition. At the low pressure-low temperature conditions for the other four fuels with higher fuel hydrogen contents the level of smoke was below the threshold of visible smoke. At the high temperature conditions and with 150 Btu per pound heat input rate the level of smoke was also below the threshold for visible smoke.

Comparisons of the effect of methods of fuel introduction on NO_x and NO emissions are shown in Figures 32 to 37. The effect of differences in the method of fuel introduction on NO_x and NO are minor but pressure atomized fuels produce a small reduction in emissions.

The differences in CO emissions with fuel introduced to the combustor by pressure atomization or prevaporization are shown in Figures 38, 39, and 40. In Program 1 with a heat input rate of 300 Btu per pound of air and an inlet air temperature of 400 F CO emissions, with one exception, increased with pressure atomized fuel. At the low temperature-low pressure conditions the increase in CO emissions became smaller as fuel hydrogen increased. At 1000 F inlet air temperature the change in CO emissions was very small with a slight decrease with pressure atomized fuels. At a heat input rate of 150 Btu per pound of air CO emissions were lower with pressure atomized fuel than with prevaporized fuel and the largest reductions were shown with the high inlet air humidity.

9.3. Effect of Inlet Air Humidity

The effects of inlet air humidity on flame radiance and exhaust emissions of NO_x, NO, and CO with each of the five test fuels are shown in Figures 41 to 50. No statistically significant effect of inlet air humidity on smoke emissions was found with any of the five fuels.

With one exception, an increase in inlet air humidity from 0.002 to 0.042 pounds of water per pound of dry air decreased total radiant energy.

An increase in inlet air humidity from 0.002 to 0.042 pounds of water per pound of dry air decreased NO_x and NO emissions. The decrease in emissions varied with fuels and operating variables with the magnitude of the decrease being from 6 to 9 pounds of NO_x per 1000 pounds of fuel. The range in humidities is from 14 to 294 grains per pound of dry air or from 10 per cent relative humidity at 76 F to 100 per cent relative humidity at 100 F. The range in humidities could be encountered with seasonal and geographic changes

and span the 75 grains of water per pound of dry air that the Environmental Protection Agency has adopted as a standard humidity. It is apperent that intake air humidity is an important factor in NO_x emissions; however, additional data are needed to provide a single correction factor for adjusting the level of NO_x emissions to a fixed level.

In Program 1 with a heat input rate of 300 Btu per pound of air the effect of an increase in inlet air humidity was small and inconsitent although in most comparisons the CO emissions increased with an increase in humidity over the range investigated. As fuel hydrogen content increased the effect of humidity on CO emissions tended to increase. In the small program CO emissions increased with humidity and the rate of increase was greater with a heat input rate of 150 Btu per pound of air than with a heat input rate of 300 Btu per pound of air.

9.4. Effect of Operating Variables

Comparisons of the effects of inlet air temperature, combustor pressure, and heat input rate on total radiant energy and emissions are shown for Fuel A and the comparisons are shown in Figures 51 to 61. While the comparisons are shown for Fuel A only, comparisons for the other fuels may be obtained from the equations if desired.

In Program 1 with a heat input rate of 300 Btu per pound of air an increase in inlet air temperature from 400 to 1000 F increases total radiant energy and the rate of increase was greater with pressure atomized fuel than with prevaporized fuel. With a heat input rate of 150 Btu per pound of air total radiant energy decreased with an increase in inlet air temperature from 600 to 800 F. An increase in combustor pressure from 7.5 to 15.0 atmospheres increased total radiant energy with the rate of increase being greater with pressure atomized fuel than with prevaporized fuel. An increase in combustor pressure in the small program from 10.0 to 12.5 atmospheres increased total radiant energy.

In Program 1 smoke optical density is below the threshold of visible smoke at a combustor pressure of 7.5 atmospheres. At 15.0 atmospheres pressure an increase in inlet air temperature from 400 to 1000 F decreased smoke optical density to below the threshold of visible smoke. The rate of decrease was greater with pressure atomized fuel than with prevaporized fuel. In the small program smoke optical density was below the level of visible smoke at both of the temperature and pressure comparisons. In Program 1 an increase in combustor pressure from 7.5 to 15.0 atmospheres increased smoke optical density at the low temperature conditions and the rate of increase in smoke optical density was greater with pressure atomized fuel than with prevaporized fuel.

In Program 1 an increase in inlet air temperature from 400 to 1000 F increased NO_x and NO emissions with the rates of increase being greater at the higher pressure. In the small program an increase in inlet air temperature from 600 to 800 F increased NO_x and NO emissions. Increasing combustor pressure from 7.5 to 15.0 atmospheres increased NO_x and NO emissions at the higher temperature but had only a slight effect on the emissions at the low inlet air temperature. In the small program an increase in combustor from 10.0 to 12.5 atmospheres increased NO_x and NO emissions slightly.

An increase in inlet air temperature decreased CO emissions in each of the comparisons although the rate of decrease was greater in Program 1. In Program 1 a change in combustor pressure had only a small effect on CO emissions at the high temperature conditions. At low inlet air temperature with prevaporized fuel an increase in combustor pressure decreased CO emissions and with pressure atomized fuel CO emissions decreased with a small increase in combustor pressure and then increased rapidly. At high pressure and low temperature vaporization and combustion may be delayed to the extent that combustion is not completed in the time available in the combustor. In the small program a change in combustor pressure from 10.0 to 12.5 atmospheres had only a small effect on CO emissions.

An increase in heat input rate from 150 to 300 Btu per pound of air increased total radiant energy in all comparisons; however, the rate of increase at low temperature with pressure atomized fuel was considerably less than at the other combinations of operating conditions. At the high heat input rate with low inlet air temperature vaporization of fuel and combustion may have been delayed and peak emissions may have occurred past the point of detection in the combustor. An increase in heat input rate from 150 to 300 Btu per pound of air increased smoke optical density but the level of smoke was still below the threshold of visible smoke at the highest level of heat input. An increase in heat input rate from 150 to 300 Btu per pound of air decreased NO_x and NO emissions at low levels of inlet air humidity and had very little effect at high levels of inlet air humidity. The lower levels of NO_x and NO emissions with pressure atomized fuel may have been due in part to cooling of the mixture by vaporization of the fuel. CO emissions were decreased with an increase in heat input rate from 150 to 300 Btu per pound of air except at low inlet air temperature with low inlet air humidity and pressure atomized fuel. At the low heat input rates CO emissions were the lowest at these conditions but as the heat input rate was increased a delay in vaporization of a portion of the fuel may have retarded complete combustion.

TABLE 18

ESTIMATED EMPIRICAL RELATIONSHIPS AND DESCRIPTIVE VALUES FOR FLAME RADIATION

Fuel	Empirical Relationship, Y = Flame Radiation, Btu/ft²/hr x 10^{-3}	$\bar{Y}$	$\hat{\sigma}_Y$	R^2	SEE	$\hat{\sigma}_E$
A	Y = -69.78 + 16.76815*P - 0.08329425*T - 3.951562*W + 190.2961*F - 36.89989*F*P - 0.03259233*F*T + 0.01074347*F*P*T + 0.0001790813*T*T + 1.175467*F*P*P - 0.465*P*W - 0.00002461833*P*T*T + 0.02909383*P*T - 0.5877333*P*P	135.10	46.5	0.96	9.7	13.4
B	Y = 82.47 - 8.231067*P - 0.3008123*T - 2.148125*W + 19.0855*F + 0.007641333*F*P*T - 0.027265*F*T - 0.008946875*T*W - 0.00003294167*P*T*T + 0.04839033*P*T + 0.0003019479*T*T - 5.348933*P*F	104.8	45.6	0.97	7.8	13.4
C	Y = -1.88 - 1.145708*P + 0.1622592*T - 3.572812*W -38.45583*F + 0.04381042*F*T - 0.007975781*T*W + 0.4179167*P*P	130.9	48.5	0.95	11.65	13.4
D	Y = -129.40 + 32.5799*P - 0.01482125*T - 7.506953*W + 230.5042*F - 0.02732417*F*T + 0.01060233*F*P*T - 0.0000161042*P*T*T + 1.631833*F*P*P + 0.0001262031*T*T - 46.48438*F*P - 1.231333*P*P + 0.01795342*P*T	149.0	44.0	0.97	8.3	13.4
E	Y = -11.73 + 5.17766*P - 0.150062*T + 1.097688*W + 24.94955*F - 0.065024*F*T + 0.01192813*F*P*T - 0.0000236225*P*T*T + 0.0001957167*T*T - 0.51755*P*W - 6.521493*F*P + 0.03202883*P*T - 0.2911*P*P - 0.004679375*T*W	99.2	42.5	0.97	8.3	13.4

Notes:
P = Combustor pressure, atm. (Range: P = 7.5 - 15.0)
T = Inlet air temperature, F. (Range: T = 400 - 1000)
H = Heat input, Btu/lb air. (Range: H = 300)
W = Inlet air humidity, lbs water/lb dry air x 100. (Range: W = 0.2 - 4.2)
F = Method of fuel induction, F = 0 = Prevaporized and F = 1 = Atomized.

TABLE 19

ESTIMATED EMPIRICAL RELATIONSHIP AND DESCRIPTIVE VALUES FOR SMOKE EMISSION

Fuel	Empirical Relationship, Y = Smoke Optical Density + 1.0, Von Brand Smokemeter	$\overline{\text{Log } Y}$	$\sigma_{\text{Log } Y}$	R^2	SEE	$\hat{\sigma}_E$
A	Log Y = -0.281527 + 0.04031366*P + 0.0003846459*T + 0.04604476*F - 0.00001098779*P*T - 0.00002472673*F*P*T - 0.0000002348732*T*T + 0.002424507*F*P*P + 0.0005319588*F*T - 0.0000002276821*F*T*T - 0.0372427*P*F - 0.001212254*P*P	0.06878	0.04508	0.66	0.02725	0.01414
B	Log Y = 0.1616018 - 0.05277925*P - 0.0002094147*T + 0.1005453*F - 0.00002399794*F*P*T + 0.0001785279*F*T - 0.0000002489487*T*T + 0.0001104443*P*T + 0.001781845*F*P*P - 0.000005047553*T*P*P - 0.02329296*P*F + 0.002642368*P*P	0.04380	0.03398	0.62	0.02164	0.01414
C	Log Y = -0.2405374 + 0.03652374*P + 0.0002559527*T + 0.04250505*F - 0.000006208267*P*T + 0.0005112028*F*T - 0.0000001544632*T*T + 0.002370147*F*P*P - 0.00002834343*F*P*T - 0.0000002048474*F*T*T -0.001185074*P*P - 0.03348791*P*F	0.06114	0.03806	0.76	0.01966	0.01414
D	Log Y = 0.08879873 - 0.02534922*P - 0.0001556505*T + 0.3560984*F + 0.00007970426*P*T - 0.00009069804*F*T + 0.002311979*F*P*P - 0.000000181748*T*T - 0.000004321935*T*P*P + 0.001869365*P*P - 0.05201952*P*F	0.07789	0.04780	0.70	0.02738	0.01414
E	Log Y = -0.3031977 + 0.03565079*P + 0.0004026249*T +0.1478234*F - 0.00001087644*P*T - 0.000000218804 2*T*T + 0.0001085618*F*T + 0.001947742*F*P*P - 0.00001443217*F*P*T - 0.0009736712*P*P - 0.03372168*P*F	0.04130	0.03253	0.71	0.01824	0.01414

Notes:

P = Combustor pressure, atm. (Range: P = 7.5 - 15.0)
T = Inlet air temperature, F. (Range: T = 400 - 1000)
H = Heat input, Btu/lb air. (Range: H = 300)
W = Inlet air humidity, lbs water/lb dry air x 100. (Range: W = 0.2 - 4.2)
F = Method of fuel induction, F = 0 = Prevaporized and F = 1 = Atomized.

TABLE 20

ESTIMATED EMPIRICAL RELATIONSHIPS AND DESCRIPTIVE VALUES FOR NO_x EMISSION INDEX

Fuel	Empirical Relationship, $Y = NO_x$ Emission Index, lbs/1000-lbs fuel	$\overline{\text{Log Y}}$	$\hat{\sigma}_{\text{Log Y}}$	R^2	SEE	$\hat{\sigma}_E$
A	Log Y = 0.5082276 + 0.02083302*P + 0.0003341613*T - 0.07524748*W - 0.1279032*F + 0.00002944609*P*T + 0.0001155604*F*T + 0.0000002557767*T*T - 0.001481262*P*P	0.95842	0.27722	0.99	0.02823	0.02489
B	Log Y = 0.5236132 - 0.002623545*P + 0.0006051611*T - 0.07698379*W - 0.1134258*F + 0.00001692992*P*T + 0.00009389131*F*T + 0.0000001761692*T*T	0.95295	0.27928	0.99	0.02470	0.02489
C	Log Y = 0.6023549 - 0.009544675*P + 0.0004999546*T - 0.07636011*W - 0.1091078*F + 0.00002459775*P*T + 0.0001131706*F*T + 0.0000001824158*T*T	0.95422	0.27798	0.99	0.02407	0.02489
D	Log Y = 0.7898146 - 0.03079469*P - 0.00009368711*T - 0.0781347*W + 0.00163764*F + 0.00009727628*P*T - 0.0002882666*F*T + 0.0000006147439*T*T + 0.000000293652*F*T*T - 0.00000005310672*P*T*T	0.96038	0.27978	0.99	0.02671	0.02489
E	Log Y = 0.6316809 - 0.01049784*P + 0.0004446142*T - 0.07680686*W - 0.09707018*F + 0.00002368915*P*T + 0.0001056607*F*T + 0.0000002336234*T*T	0.95599	0.27852	0.99	0.02612	0.02489

Notes:

P = Combustor pressure, atm. (Range: P = 7.5 - 15.0)
T = Inlet air temperature, F. (Range: T = 400 - 1000)
H = Heat input, Btu/lb air. (Range: H = 300)
W = Inlet air humidity, lbs water/lb dry air x 100. (Range: W = 0.2 - 4.2)
F = Method of fuel induction, F = 0 = Prevaporized and F = 1 = Atomized.

TABLE 21

ESTIMATED EMPIRICAL RELATIONSHIPS AND DESCRIPTIVE VALUES FOR NO EMISSION INDEX

Fuel	Empirical Relationship, Y = NO Emission Index, lbs/1000-lbs fuel	$\overline{\text{Log } Y}$	$\hat{\sigma}_{\text{Log } Y}$	R^2	SEE	$\hat{\sigma}_E$
A	Log Y = -0.1717928 + 0.0440157*P + 0.001577601*T - 0.07288764*W + 0.1696648*F - 0.000009553521*P*T + 0.0000004602326*F*T*T - 0.0009436079*P*P - 0.0000002301163*T*T - 0.0006443256*T*F	0.92464	0.28988	0.99	0.02664	0.03049
B	Log Y = -0.1645094 + 0.03229473*P + 0.001646528*T - 0.07172196*W + 0.07247835*F - 0.00002216019*P*T + 0.0000003455784*F*T*T - 0.0004266741*F*T - 0.0000001727892*T*T	0.90599	0.29721	0.99	0.02852	0.03049
C	Log Y = -0.1115123 + 0.0237861*P + 0.001642834*T - 0.06100554*W + 0.1296074*F - 0.00001208702*P*T - 0.00001590475*T*W + 0.0000004590307*F*T*T - 0.0005744363*F*T - 0.0000002295154*T*T	0.91592	0.29635	0.99	0.02661	0.03049
D	Log Y = -0.1098703 + 0.04448267*P + 0.001494305*T - 0.07523541*W + 0.3252679*F + 0.000000322345*F*T*T + 0.0000282866*F*P*T - 0.0007017047*F*T - 0.02406884*F*P - 0.0008266193*P*P - 0.0000001611725*T*T - 0.00001414331*P*T	0.94163	0.28989	0.99	0.02504	0.03049
E	Log Y = -0.1018012 + 0.02093403*P + 0.001673781*T - 0.05543536*W + 0.1744618*F - 0.00001088999*P*T - 0.00002366088*T*W + 0.0000005167381*F*T*T - 0.0006704596*F*T - 0.0000002583691*T*T	0.91377	0.29141	0.99	0.02899	0.03049

Notes:

P = Compustor pressure, atm. (Range: P = 7.5 - 15.0)
T = Inlet air temperature, F. (Range: T = 400 - 1000)
H = Heat input, Btu/lb air. (Range: H = 300)
W = Inlet air humidity, lbs water/lb dry air x 100. (Range: W = 0.2 - 4.2)
F = Method of fuel induction, F = 0 = Prevaporized and F = 1 = Atomized.

TABLE 22

ESTIMATED EMPIRICAL RELATIONSHIPS AND DESCRIPTIVE VALUES FOR CO EMISSION INDEX

Fuel	Empirical relationship, Y = CO Emission Index, lbs/1000-lbs fuel	$\overline{Log\ Y}$	$\hat{\sigma}_{Log\ Y}$	R^2	SEE	$\hat{\sigma}_E$
A	Log Y = 2.674567 - 0.08572861*P - 0.004833868*T + 0.03045297*W + 0.001001116*F + 0.002774744*F*T + 0.0095765*F*P*P - 0.0002110027*P*P + 0.000002467401*T*T - 0.000001391464*F*T*T - 0.0001065889*F*P*T - 0.0000001085103*P*T*T - 0.02249039*F*W - 0.1408590*P*F + 0.0002052089*P*T	0.65352	0.24964	0.89	0.08897	0.06797
B	Log Y = 2.134762 - 0.00860966*P - 0.003583411*T - 0.09141404*W + 0.6084472*F + 0.002568495*F*T + 0.01341609*F*P*P - 0.000001445754*F*T*T + 0.000001389626*T*T + 0.01550679*W*W + 0.005333846*P*W - 0.002848023*P*P - 0.00003939096*T*W*W - 0.2399954*P*F + 0.0001733202*T*W + 0.00007763096*P*T - 0.00008838099*F*P*T	0.63205	0.24438	0.91	0.07671	0.06797
C	Log Y = 1.710033 + 0.01764519*P - 0.003092205*T + 0.09751775*W + 0.445863*F + 0.002738608*F*T - 0.000001607933*F*T*T + 0.01202012*F*P*P - 0.002039522*P*P + 0.000001332683*T*T - 0.01120918*W*W - 0.0244115*F*W - 0.00008069731*F*P*T - 0.2139645*P*F + 0.00004034865*P*T	0.64448	0.25746	0.90	0.08642	0.06797
D	Log Y = 1.838186 + 0.005572017*P - 0.002970048*T + 0.03587321*W + 0.7931655*F + 0.002652721*F*T + 0.01399869*F*P*P - 0.000001695368*F*T*T - 0.001621155*P*P + 0.004765785*P*W + 0.000001276213*T*T - 0.02165020*F*W - 0.009087740*W*W - 0.00005834068*F*P*T - 0.2741321*P*F + 0.00002917034*P*T	0.66382	0.26945	0.92	0.07973	0.06797
E	Log Y = 1.787047 - 0.02713883*P - 0.00229215*T + 0.02632815*W + 0.2150832*F + 0.01127096*F*P*P + 0.002831387*F*T - 0.0006656029*P*P + 0.006292416*F*W - 0.01517362*W*W - 0.000001572599*F*T*T - 0.00008077594*F*P*T - 0.1970534*P*F + 0.0000007862995*T*T + 0.00004038797*P*T	0.63491	0.23423	0.87	0.08812	0.06797

TABLE 22 (Continued)

Notes:

P = Combustor pressure, atm. (Range: P = 7.5 - 15.0)
T = Inlet air temperature, F. (Range: T = 400 - 1000)
H = Heat input, Btu/lb air. (Range: H = 300)
W = Inlet air humidity, lbs water/lb dry air x 100. (Range: W = 0.2 - 4.2)
F = Method of fuel induction, F = 0 = Prevaporized and F = 1 = Atomized.

TABLE 23

ESTIMATED EMPIRICAL RELATIONSHIPS AND DESCRIPTIVE VALUES FOR FLAME RADIATION

Fuel	Empirical Relationship, Y = Flame Radiation, Btu/ft^2/hr x 10^{-3}	$\bar{Y}$	$\hat{\sigma}_Y$	R^2	SEE	$\hat{\sigma}_E$
A	Y = -73.964 + 5.736667*P - 0.1620833*T + 8.85312*W + 0.31475*H + 352.7345*F + 0.0009744444*T*H - 0.07291667*W*H + 0.001147778*H*F*T - 1.460306*F*H + 0.06791667*H*F*W - 0.25625*T*F - 15.28125*W*F	96.9	54.6	0.98	9.4	13.4
B	Y = -46.698 + 5.626667*P - 0.144625*T + 10.60313*W + 0.05193611*H + 237.1696*F - 0.0009522222*T*H - 0.9638278*F*H + 0.0008255556*H*T - 0.07370833*W*H + 0.06275*H*F*W - 0.18575*T*F - 14.11875*W*F	74.0	40.9	0.97	7.8	13.4
C	Y = -7.810948 - 0.2767417*P - 0.1302104*T - 8.292656*W + 0.3170942*H + 270.8803*F - 1.659503*F*H + 0.0007618333*T*H + 0.001524278*H*T*F+0.0701375*H*W*F - 0.06767917*W*H - 3.32825*F*P*W + 17.54531*F*W + 12.29448*F*P - 0.3429625*T*F + 1.664125*P*W	92.1	47.9	0.97	9.4	13.4
D	Y = -62.55285 + 3.766258*P - 0.1547688*T - 14.88469*W + 0.4450876*H + 389.3501*F -1.913631*F*H + 0.0008326111*T*H + 0.001611833*H*F*T + 0.07069583*H*F*W + 16.26531*F*W - 3.28325*P*F*W - 0.3626625*T*F - 0.03534792*W*H + 1.641625*P*W + 7.22315*P*F	107.9	60.3	0.98	9.4	13.4
E	Y = +71.26302 + 7.099167*P - 0.3091771*T + 3.679688*W - 0.3981993*H + 35.55208*F - 0.3315278*F*H + 0.001506528*T*H - 0.04271875*W*H + 0.06689583*F*T	73.2	39.0	0.96	8.6	13.4

Notes: P = Combustor pressure, atm (Range: P = 10.0 - 12.5)
T = Inlet air temperature, F (Range: T = 600 - 800)
H = Heat input, Btu/lb air (Range: H = 150 -300)
W = Inlet air humidity, lbs water/lb dry air x 100. (Range: W = 0.2 - 4.2)
F = Method of fuel induction, F = 0 = Prevaporized and F = 1 = Atomized.

TABLE 24

ESTIMATED EMPIRICAL RELATIONSHIPS AND DESCRIPTIVE VALUES FOR SMOKE EMISSION

Fuel	Empirical Relationship, Y = Smoke Optical Density + 1.0, Von Brand Smokemeter	$\overline{\text{Log } Y}$	$\hat{\sigma}_{\text{Log } Y}$	R^2	SEE	$\hat{\sigma}_E$
A	Log Y = -0.232333 + 0.02118299*P - 0.00008111215*T + 0.1270067*F + 0.001207918*H - 0.0122295*F*P - 0.00006696897*P*H	0.04617	0.04049	0.84	0.01696	0.01414
B	Log Y = -0.4550729 + 0.0485756*P + 0.0004107793*T + 0.8480492*F + 0.000198449*H + 0.0001019926*F*P*T + 0.000154066*F*H + 0.0000007241285*T*H - 0.07846347*F*P - 0.00004152829*P*H - 0.00005099629*P*T - 0.001147417*T*F	0.03094	0.02931	0.82	0.01300	0.01414
C	Log Y = -0.3325234 + 0.02951668*P + 0.0003598759 + 0.6300125*F + 0.0003289159*H + 0.0001516126*F*H - 0.0590336*F*P + 0.00007178201*F*P*T - 0.00003589101*P*T - 0.0008075477*T*F	0.04282	0.03488	0.86	0.01386	0.01414
D	Log Y = -0.0547362 + 0.000462062*H	0.04923	0.04125	0.72	0.02202	0.01414
E	Log Y = -0.0162421 - 0.01962415*F + 0.0002505045*H	0.03031	0.02894	0.55	0.01989	0.01414

Notes:

P = Combustor pressure, atm. (Range: P = 10.0 - 12.5)
T = Inlet air temperature, F. (Range: T = 600 - 800)
H = Heat input, Btu/lb air. (Range: H = 150 - 300)
W = Inlet air humidity, lbs water/lb dry air x 100. (Range: W = 0.2 - 4.2)
F = Method of fuel induction, F = 0 = Prevaporized and F = 1 = Atomized.

TABLE 25

ESTIMATED EMPIRICAL RELATIONSHIPS AND DESCRIPTIVE VALUES FOR NO_x EMISSION INDEX

Fuel	Empirical Relationship, Y = NO_x Emission Index, lbs/1000-lbs fuel	$\overline{\text{Log } Y}$	$\hat{\sigma}_{\text{Log } Y}$	R^2	SEE	$\hat{\sigma}_E$
A	Log Y = 0.4452725 + 0.01366656*P + 0.0009898167*T − 0.1035303*W − 0.506535*F − 0.0005765224*H + 0.00009737986*W*H − 0.000002417866*H*F*T + 0.0000001663271*T*H + 0.0007125958*F*T + 0.001483719*F*H	0.98146	0.18251	0.99	0.02130	0.02489
B	Log Y = 0.09033029 + 0.05310103*P + 0.001548774*T − 0.1039203*W − 0.4465604*F − 0.001337794*H + 0.0000788046*W*H − 0.000002448582*H*F*T − 0.0000601997*P*T + 0.0005509309*T*F + 0.001714007*F*H + 0.000001224291*T*H	0.96957	0.18956	0.99	0.02059	0.02489
C	Log Y = 0.4924606 + 0.01026803*P + 0.001018603*T − 0.1058407*W − 0.4732822*F − 0.0009251391*H + 0.00009060276*W*H − 0.000002713522*H*F*T + 0.0000004674392*T*H + 0.0006105425*T*F + 0.001899465*F*H	0.97551	0.18732	0.99	0.02214	0.02489
D	Log Y = 0.6945319 − 0.01086715*P + 0.001100798*T − 0.1020536*W − 0.4314544*F − 0.001944232*H + 0.00008078194*W*H − 0.000002404725*H*F*T + 0.0001101287*P*H + 0.000000102568*T*H + 0.000541063*T*F + 0.001683307*F*H	0.98941	0.18700	0.99	0.02043	0.02489
E	Log Y = 0.3409792 + 0.008131946*P + 0.001185908*T − 0.1035433*W − 0.3491436*F − 0.0003617301*H + 0.00008287073*W*H − 0.00000199301*H*F*T − 0.00000009001713*T*H + 0.0004484273*T*F + 0.001395107*F*H	0.96264	0.18699	0.99	0.02376	0.02489

TABLE 25 (Continued)

Notes:

P = Combustor pressure, atm. (Range: P = 10.0 - 12.5)
T = Inlet air temperature, F. (Range: T = 600 - 800)
H = Heat input, Btu/lb air. (Range: H = 150 - 300)
W = Inlet air humidity, lbs water/lb dry air x 100. (Range: W = 0.2 - 4.2)
F = Method of fuel induction, F = 0 = Prevaporized and F = 1 = Atomized.

TABLE 26

ESTIMATED EMPIRICAL RELATIONSHIPS AND DESCRIPTIVE VALUES FOR NO EMISSION INDEX

Fuel	Empirical Relationship, Y = NO Emission Index, lbs/1000-lbs fuel	$\overline{\text{Log } Y}$	$\hat{\sigma}_{\text{Log } Y}$	R^2	SEE	$\hat{\sigma}_E$
A	Log Y = 0.2917928 + 0.0154401*P + 0.001160435*T - 0.1053713*W + 0.0124576*F - 0.0005371267*H + 0.0001131858*W*H - 0.0002639971*F*H	0.95768	0.18430	0.98	0.02589	0.03049
B	Log Y = 0.401223 + 0.01428837*P + 0.001060194*T - 0.1072917*W - 0.2308483*F - 0.0006833234*H + 0.0001096718*W*H + 0.0002514274*F*T	0.94118	0.19005	0.98	0.02671	0.03049
C	Log Y = 2.375692 - 0.1542867*P - 0.001682025*T - 0.1132006*W - 0.3403833*F - 0.00966825*H + 0.0001301105*W*H - 0.000001908735*H*F*T - 0.000001049185*H*P*T + 0.0004294654*T*F + 0.0000127577*T*H + 0.001336115*F*H + 0.0002360666*P*T + 0.0007344293*P*H	0.95104	0.19002	0.99	0.01976	0.03049
D	Log Y = 0.5924017 + 0.01568069*P + 0.0007881739*T - 0.1068048*W - 0.5417184*F - 0.00171819*H + 0.000107827*W*H - 0.000003127557*H*F*T + 0.0007037003*T*F + 0.000001563778*T*H + 0.00218929*F*H	0.97407	0.18548	0.99	0.02137	0.03049
E	Log Y = 0.2886387 + 0.009064549*P + 0.00123665*T - 0.1094817*W - 0.0294954 9*F - 0.0005679301*H + 0.0001210026*W*H	0.93277	0.18910	0.98	0.02652	0.03049

Notes:

P = Combustor pressure, atm. (Range: P = 10.0 - 12.5)
T = Inlet air temperature, F. (Range: T = 600 - 800)
H = Heat input, Btu/lb air. (Range: H = 150 - 300)
W = Inlet air humidity, lbs water/lb dry air x 100. (Range: W = 0.2 - 4.2)
F = Method of fuel induction, F = 0 = Prevaporized and F = 1 = Atomized.

TABLE 27

ESTIMATED EMPIRICAL RELATIONSHIPS AND DESCRIPTIVE VALUES FOR CO EMISSION INDEX

Fuel	Empirical Relationship, Y = CO Emission Index, lbs/1000-lbs fuel	$\overline{\text{Log Y}}$	$\hat{\sigma}_{\text{Log Y}}$	R^2	SEE	$\hat{\sigma}_E$
A	Log Y = 0.1506801 + 0.05665353*P - 0.0002090155*T + 0.1971185*W - 1.250896*F + 0.003055827*H - 0.000574496*W*H + 0.006695257*F*H - 0.0000007004013*T*H - 0.000008154325*H*F*T + 0.001277798*F*T - 0.0002517935*P*H	0.66377	0.20527	0.89	0.07537	0.06797
B	Log Y = 1.134036 - 0.000582183*T + 0.1981315*W - 1.743893*F - 0.0007591455*H - 0.0005468924*W*H + 0.007259121*F*H - 0.000008637187*F*H*T + 0.00000002081374*T*H + 0.001943367*T*F	0.66886	0.21369	0.90	0.07462	0.06797
C	Log Y = 0.768256 - 0.0001309166*T + 0.2027152*W - 1.31116*F + 0.001114152*H - 0.0005701132*W*H + 0.005424787*F*H - 0.000005796999*F*H*T - 0.000002366614*T*H + 0.001304325*T*F	0.67303	0.20688	0.90	0.07167	0.06797
D	Log Y = 1.131392 - 0.00070067*T + 0.1996389*W - 1.858594*F - 0.0006920069*H - 0.0005365742*W*H + 0.007809511*F*H - 0.0000094368*F*H*T + 0.0000004424098*T*H + 0.002123280*T*F	0.67778	0.20418	0.90	0.07187	0.06797
E	Log Y = 1.092301 - 0.0006005939*T+0.2094398*W - 1.780736*F -0.0002549908*H - 0.0006338609*W*H + 0.007400898*F*H - 0.000009092109*F*H*T - 0.0000001988431*T*H + 0.002045725*T*F	0.67198	0.20831	0.90	0.07023	0.06797

Notes:

P = Combustor pressure, atm. (Range: P = 10.0 - 12.5)
T = Inlet air temperature, F. (Range: T - 600 - 800)
H = Heat input, Btu/lb air. (Range: H = 150 - 300)
W = Inlet air humidity, lbs water/lb dry air x 100. (Range: W = 0.2 - 4.2)
F = Method of fuel induction, F = 0 = Prevaporized and F = 1 = Atomized.

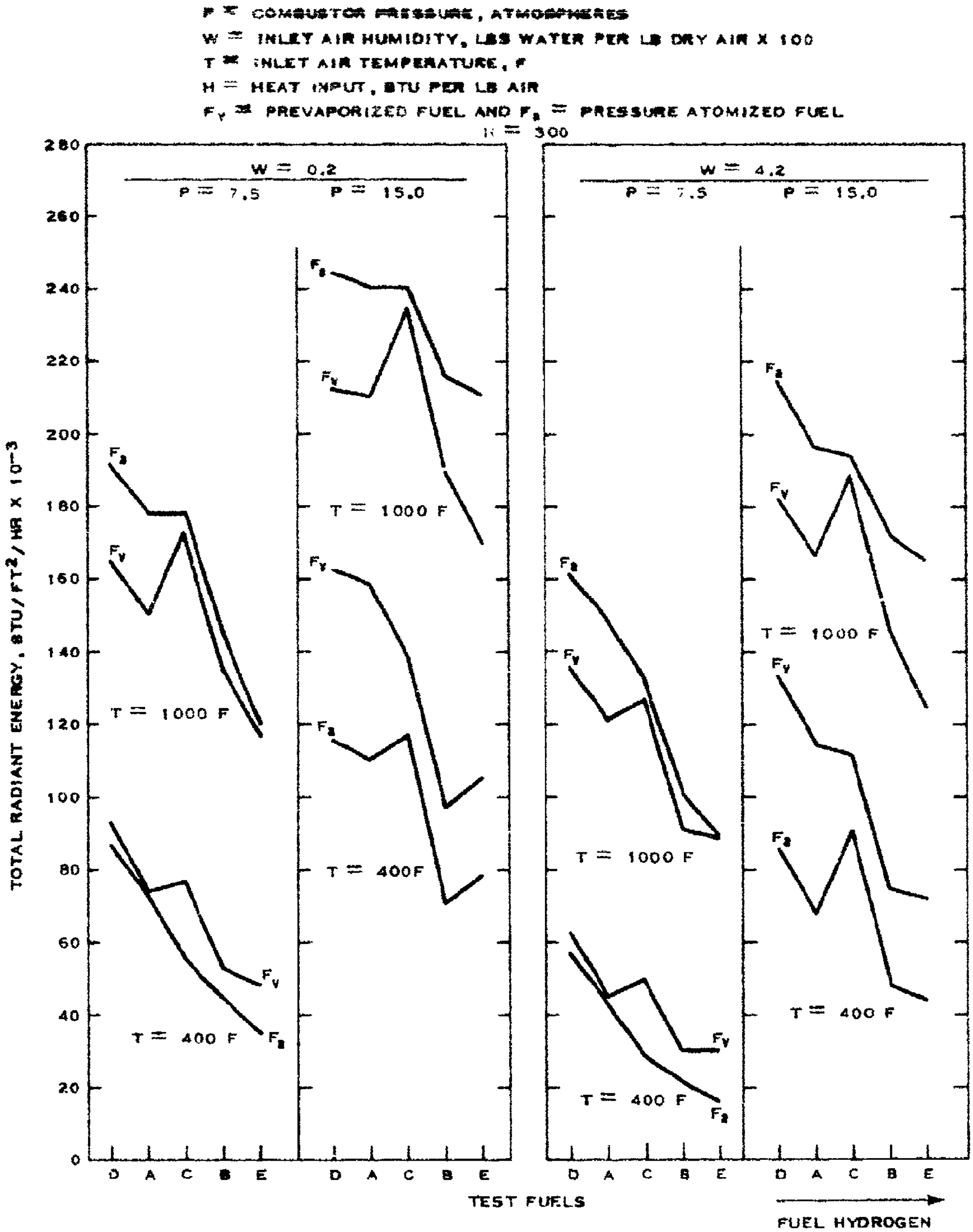

FIGURE 13
CALCULATED RADIANT ENERGY WITH FUELS AT SELECTED LEVELS OF OPERATING VARIABLES

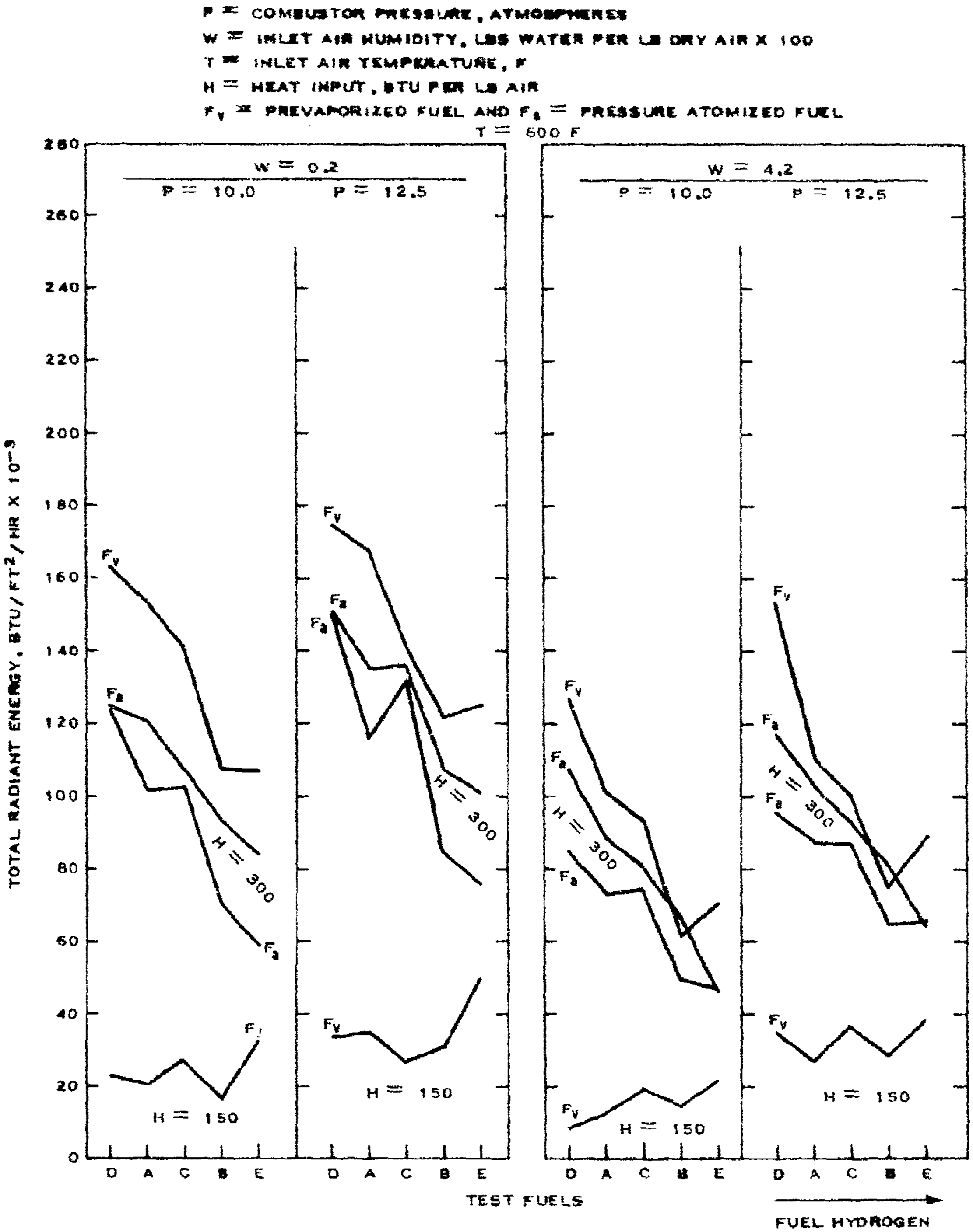

FIGURE 14
CALCULATED RADIANT ENERGY WITH FUELS AT SELECTED LEVELS OF OPERATING VARIABLES

P = COMBUSTOR PRESSURE, ATMOSPHERES
W = INLET AIR HUMIDITY, LBS WATER PER LB DRY AIR X 100
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_v = PREVAPORIZED FUEL AND F_s = PRESSURE ATOMIZED FUEL

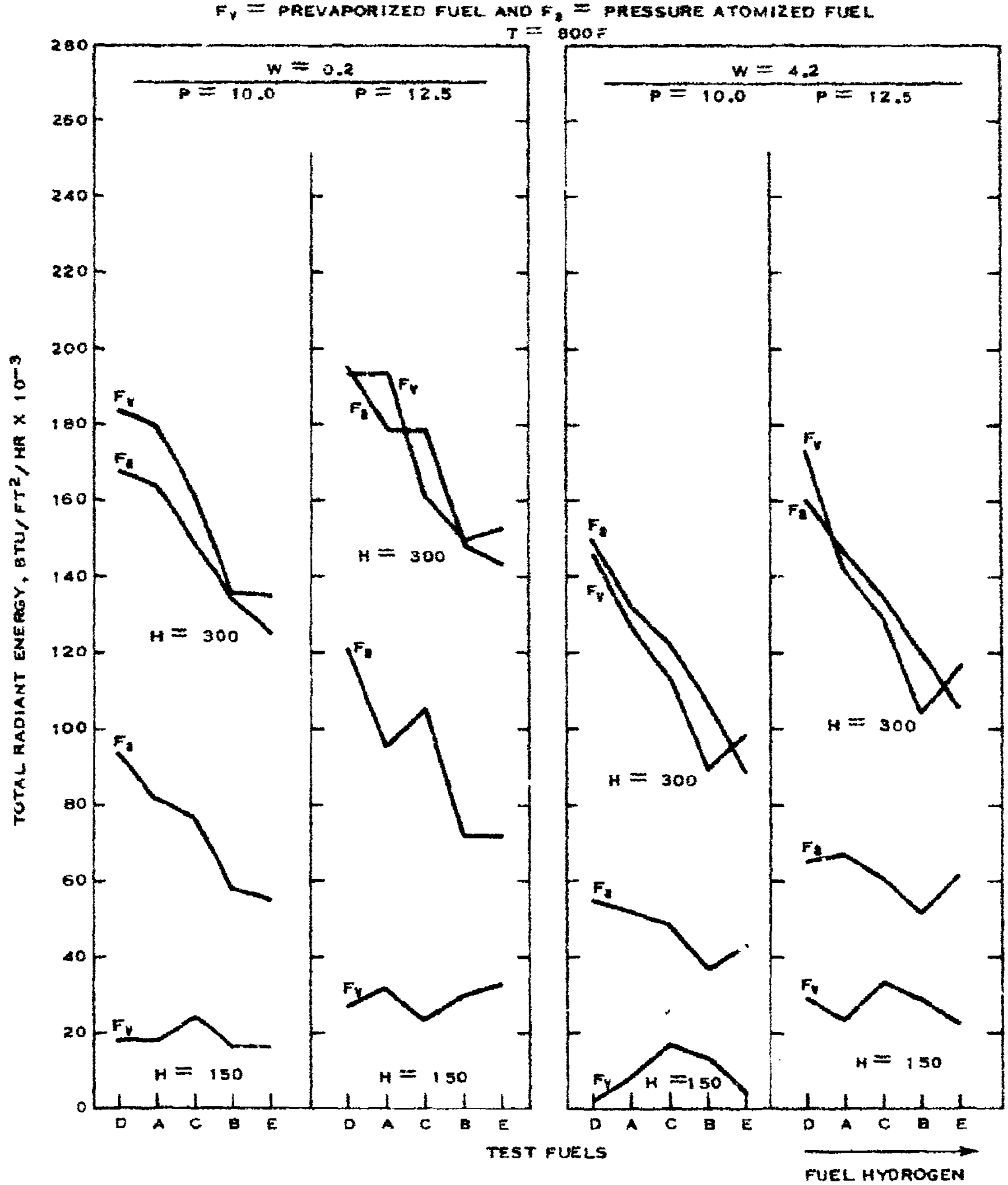

FIGURE 15
CALCULATED RADIANT ENERGY WITH FUELS AT SELECTED LEVELS OF OPERATING VARIABLES

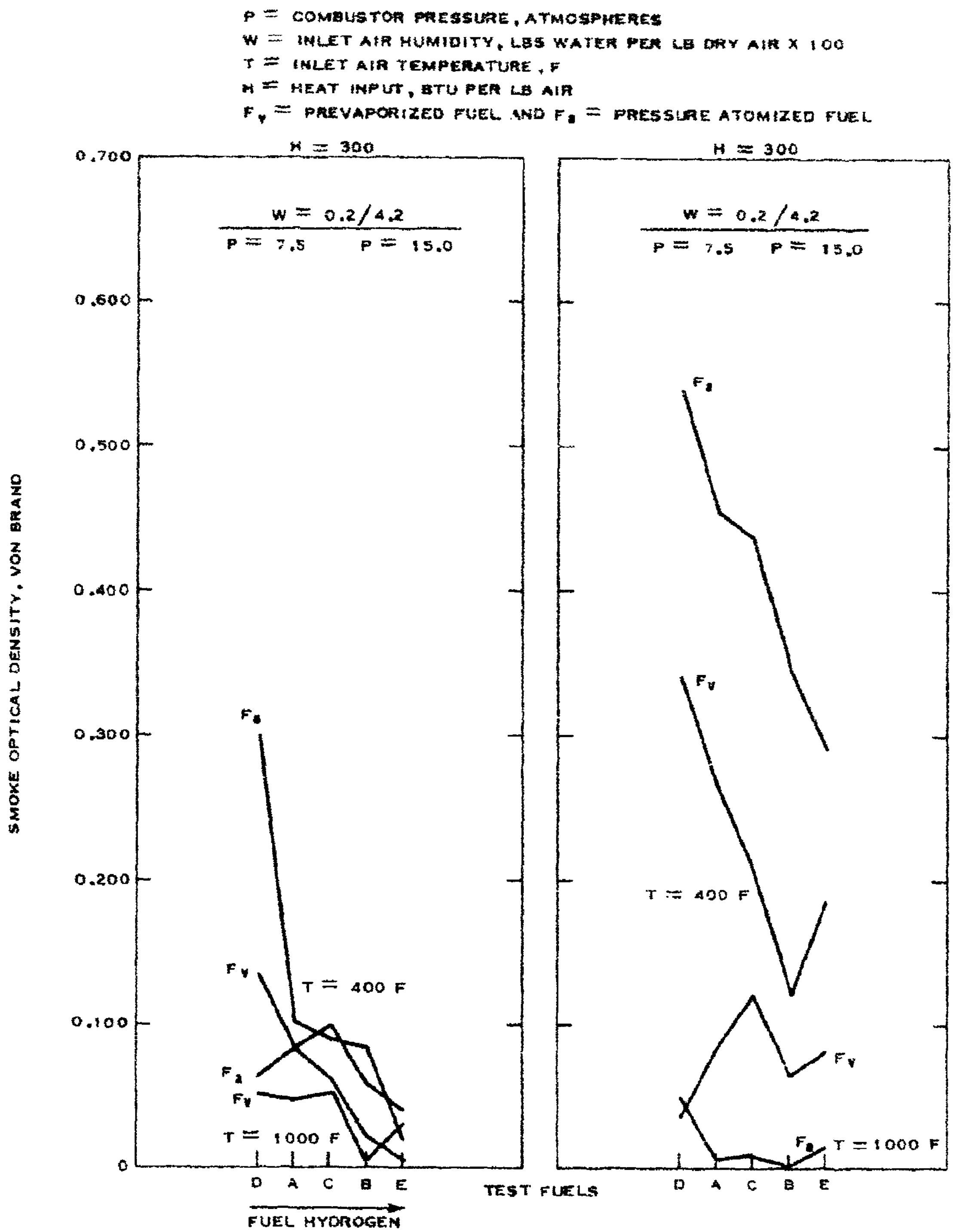

FIGURE 16
CALCULATED SMOKE EMISSIONS WITH FUELS AT SELECTED LEVELS OF OPERATING VARIABLES

P = COMBUSTOR PRESSURE, ATMOSPHERES
W = INLET AIR HUMIDITY, LBS WATER PER LB DRY AIR X 100
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_V = PREVAPORIZED FUEL AND F_S = PRESSURE ATOMIZED FUEL

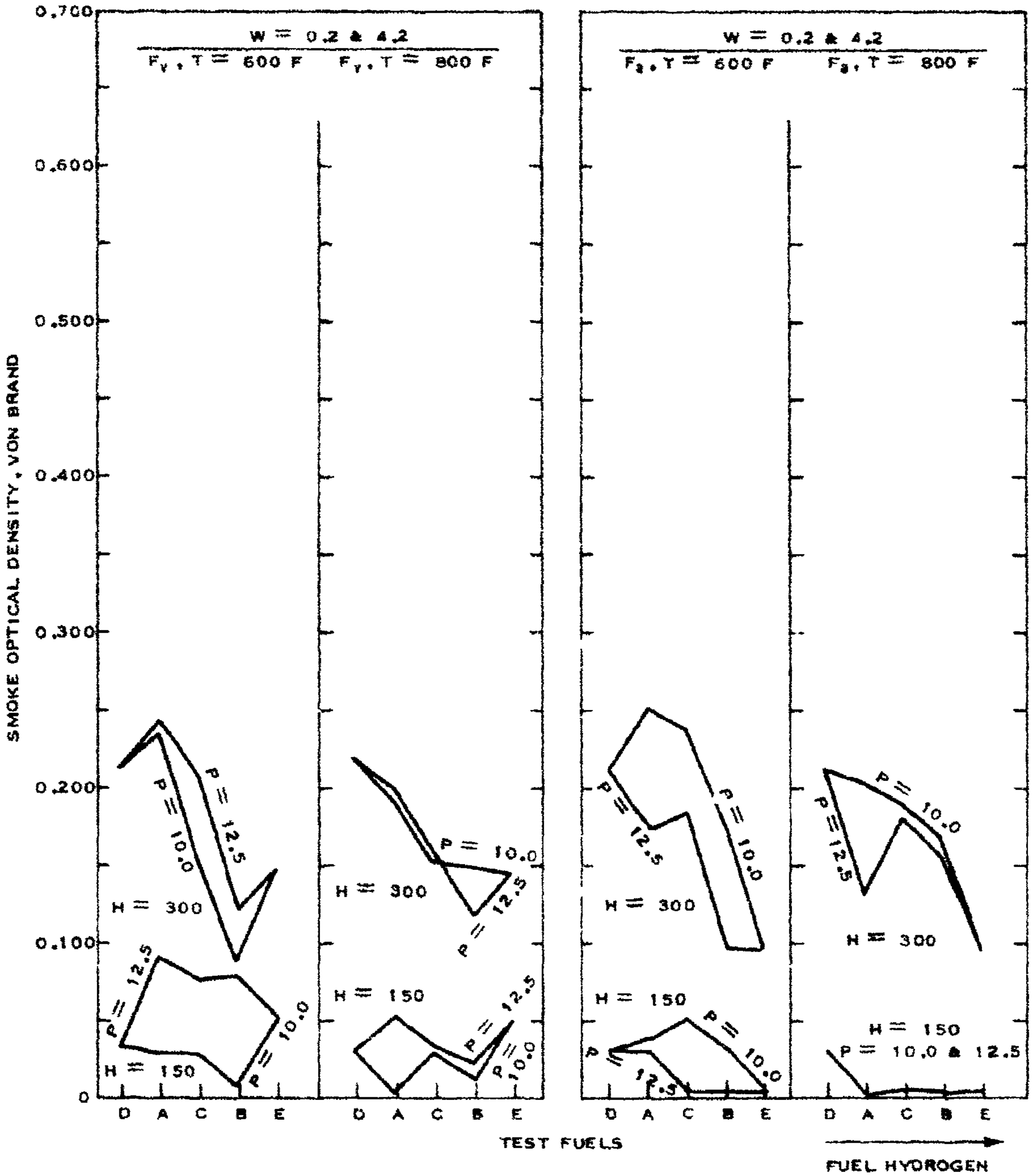

FIGURE 17
CALCULATED SMOKE EMISSIONS WITH FUELS AT SELECTED LEVELS OF OPERATING VARIABLES

P = COMBUSTOR PRESSURE, ATMOSPHERES
W = INLET AIR HUMIDITY, LBS WATER PER LB DRY AIR X 100
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_v = PREVAPORIZED FUEL AND F_a = PRESSURE ATOMIZED FUEL

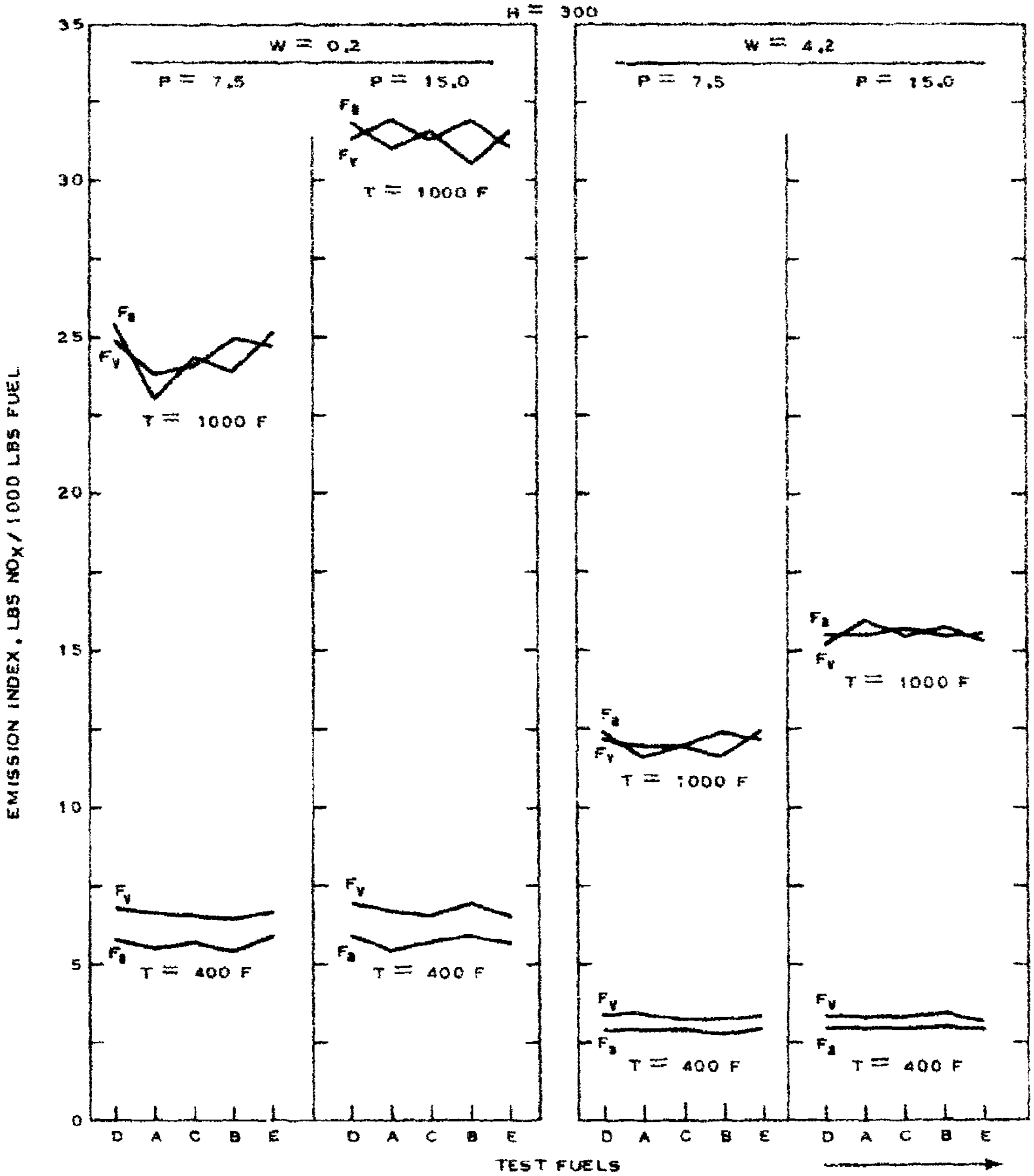

FIGURE 18
CALCULATED NO_X EMISSIONS WITH FUELS AT SELECTED LEVELS OF OPERATING VARIABLES

P = COMBUSTOR PRESSURE, ATMOSPHERES
W = INLET AIR HUMIDITY, LBS WATER PER LB DRY AIR X 100
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_v = PREVAPORIZED FUEL AND F_a = PRESSURE ATOMIZED FUEL

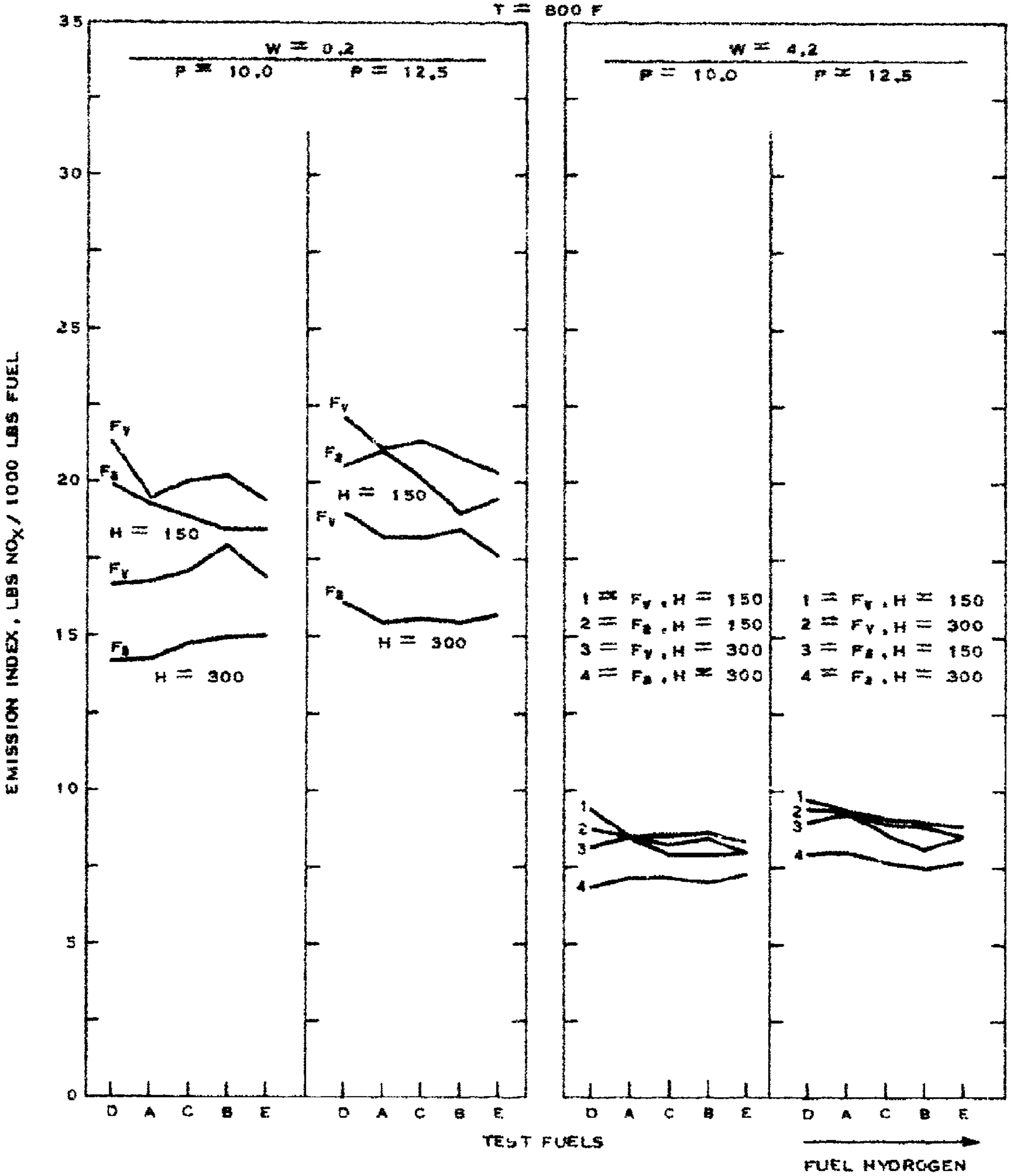

FIGURE 19
CALCULATED NO_X EMISSIONS WITH FUELS AT SELECTED LEVELS OF OPERATING VARIABLES

P = COMBUSTOR PRESSURE, ATMOSPHERES
W = INLET AIR HUMIDITY, LBS WATER PER LB DRY AIR X 100
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_v = PREVAPORIZED FUEL AND F_a = PRESSURE ATOMIZED FUEL

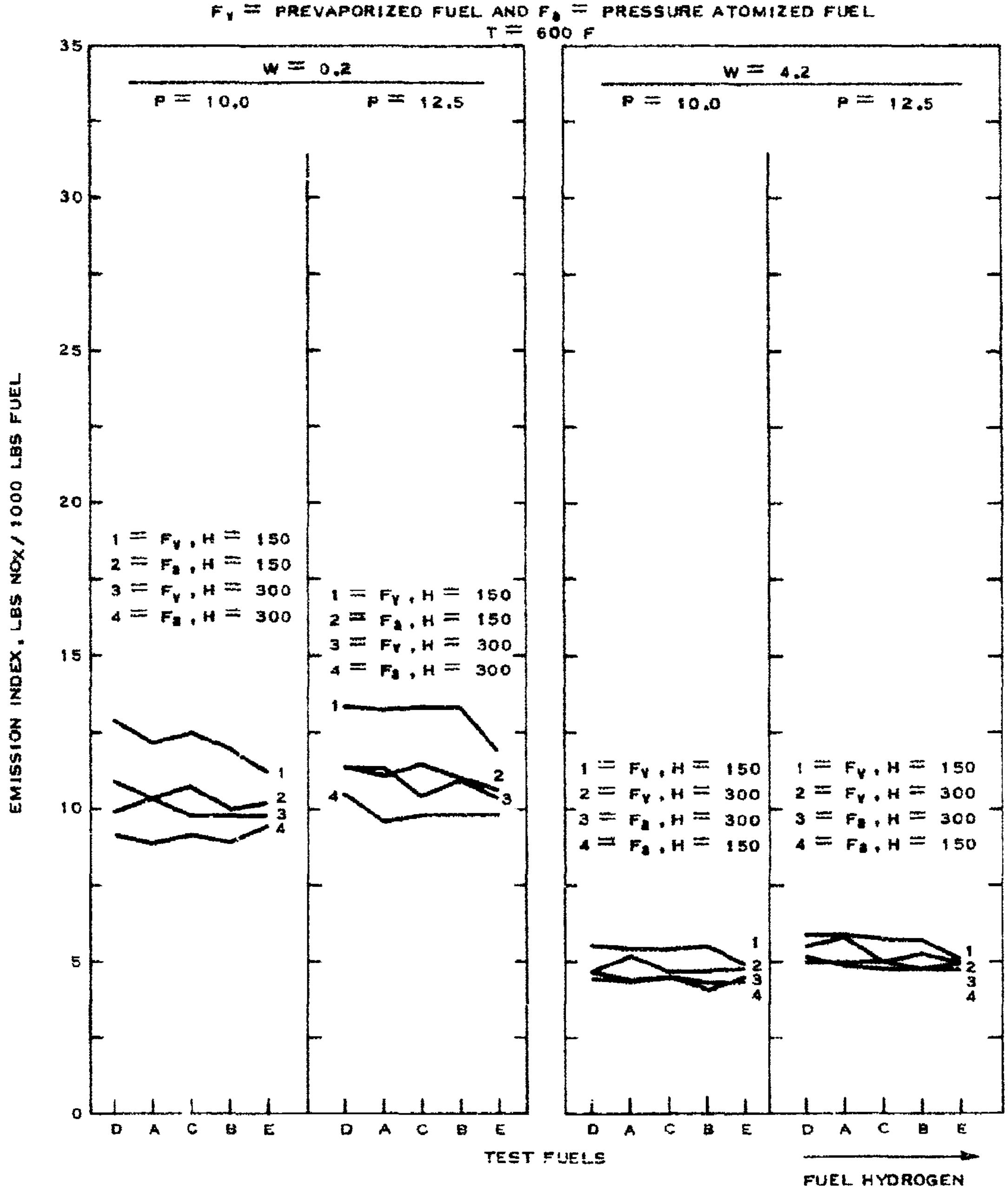

FIGURE 20
CALCULATED NO_X EMISSIONS WITH FUELS AT SELECTED LEVELS OF OPERATING VARIABLES

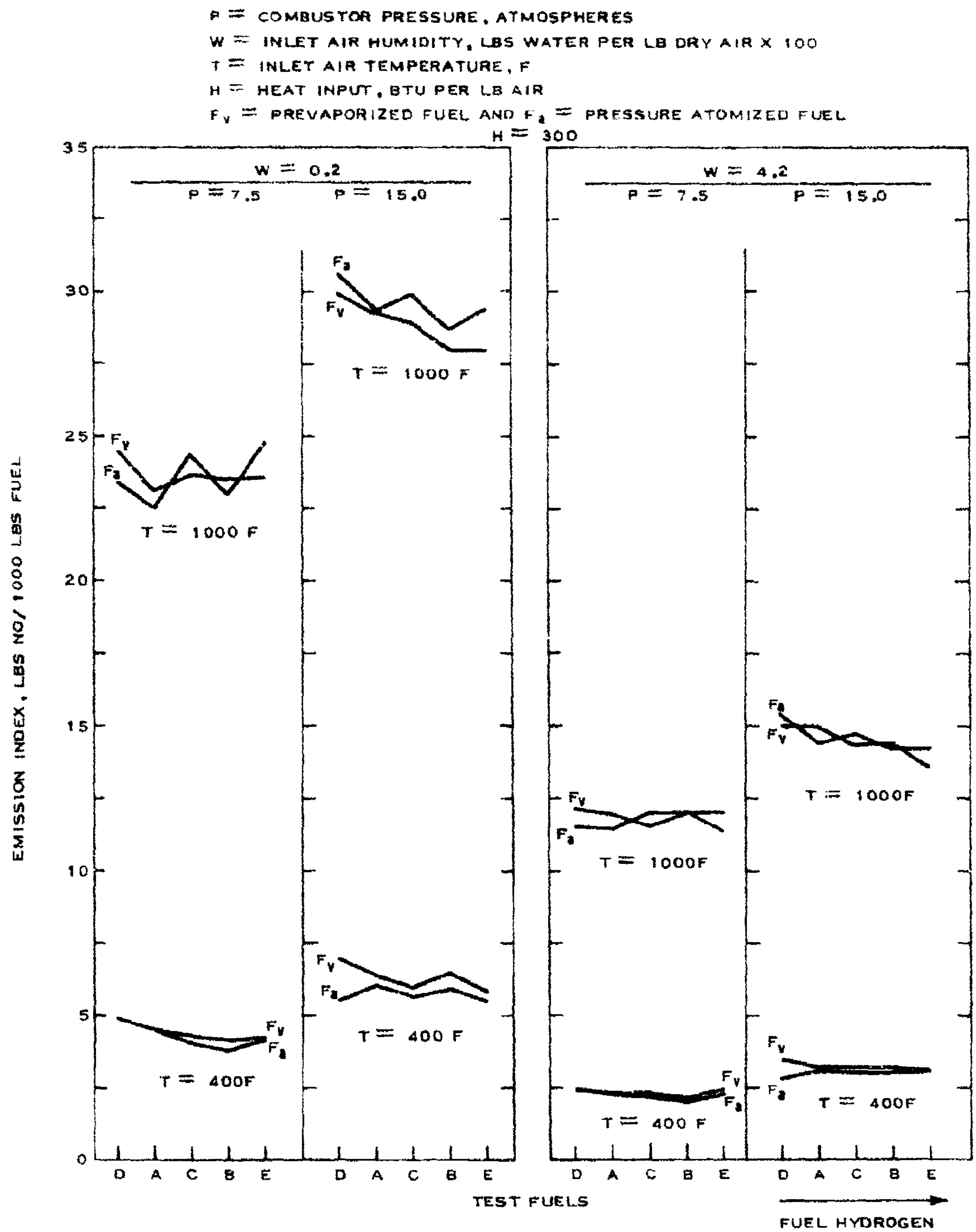

FIGURE 21
CALCULATED NO EMISSIONS WITH FUELS AT SELECTED LEVELS OF OPERATING VARIABLES

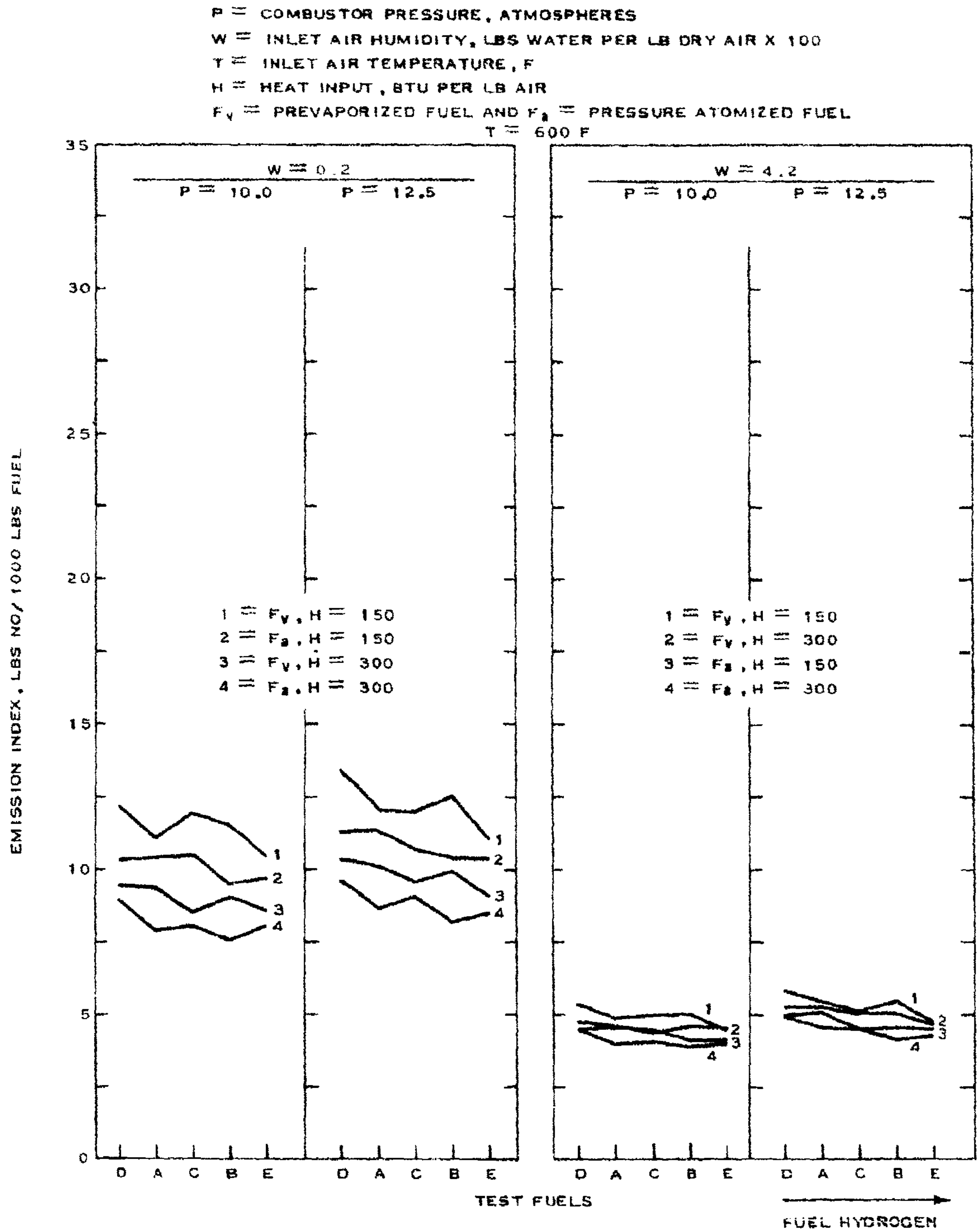

FIGURE 22
CALCULATED NO EMISSIONS WITH FUELS AT SELECTED LEVELS OF OPERATING VARIABLES

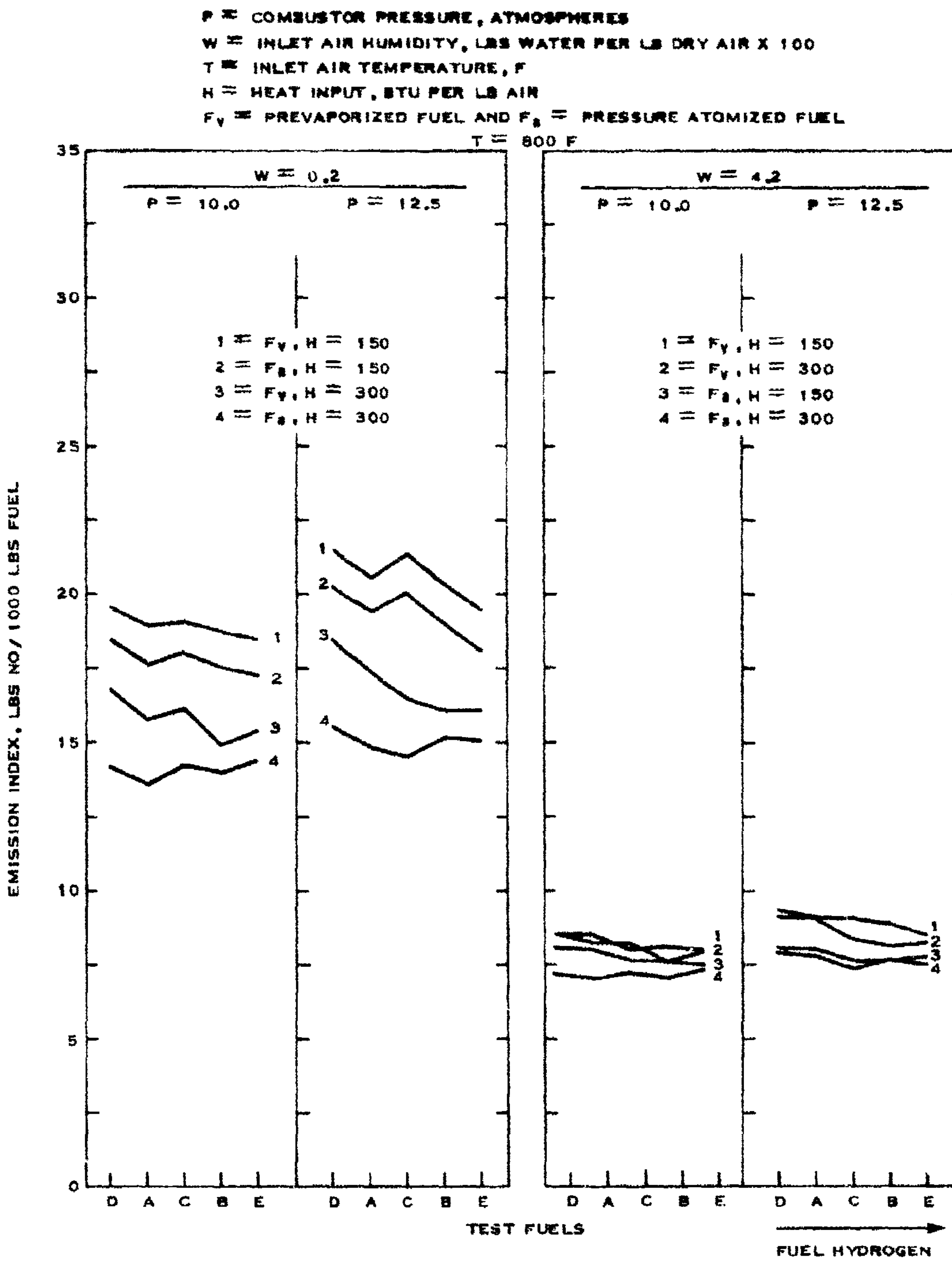

FIGURE 23
CALCULATED NO EMISSIONS WITH FUELS AT SELECTED LEVELS OF OPERATING VARIABLES

P = COMBUSTOR PRESSURE, ATMOSPHERES
W = INLET AIR HUMIDITY, LBS WATER PER LB DRY AIR X 100
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_v = PREVAPORIZED FUEL AND F_a = PRESSURE ATOMIZED FUEL

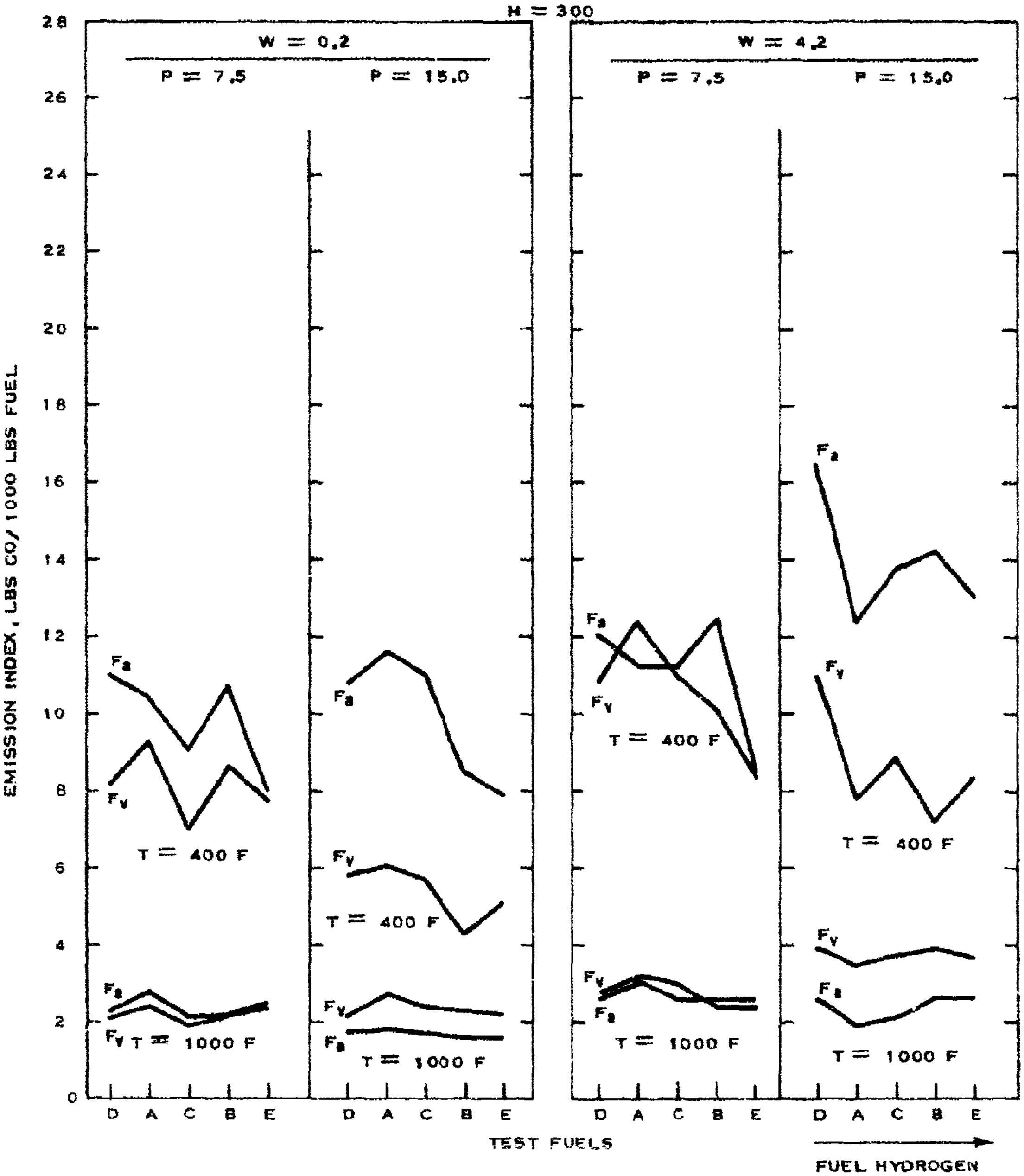

FIGURE 24
CALCULATED CO EMISSIONS WITH FUELS AT SELECTED LEVELS OF OPERATING VARIABLES

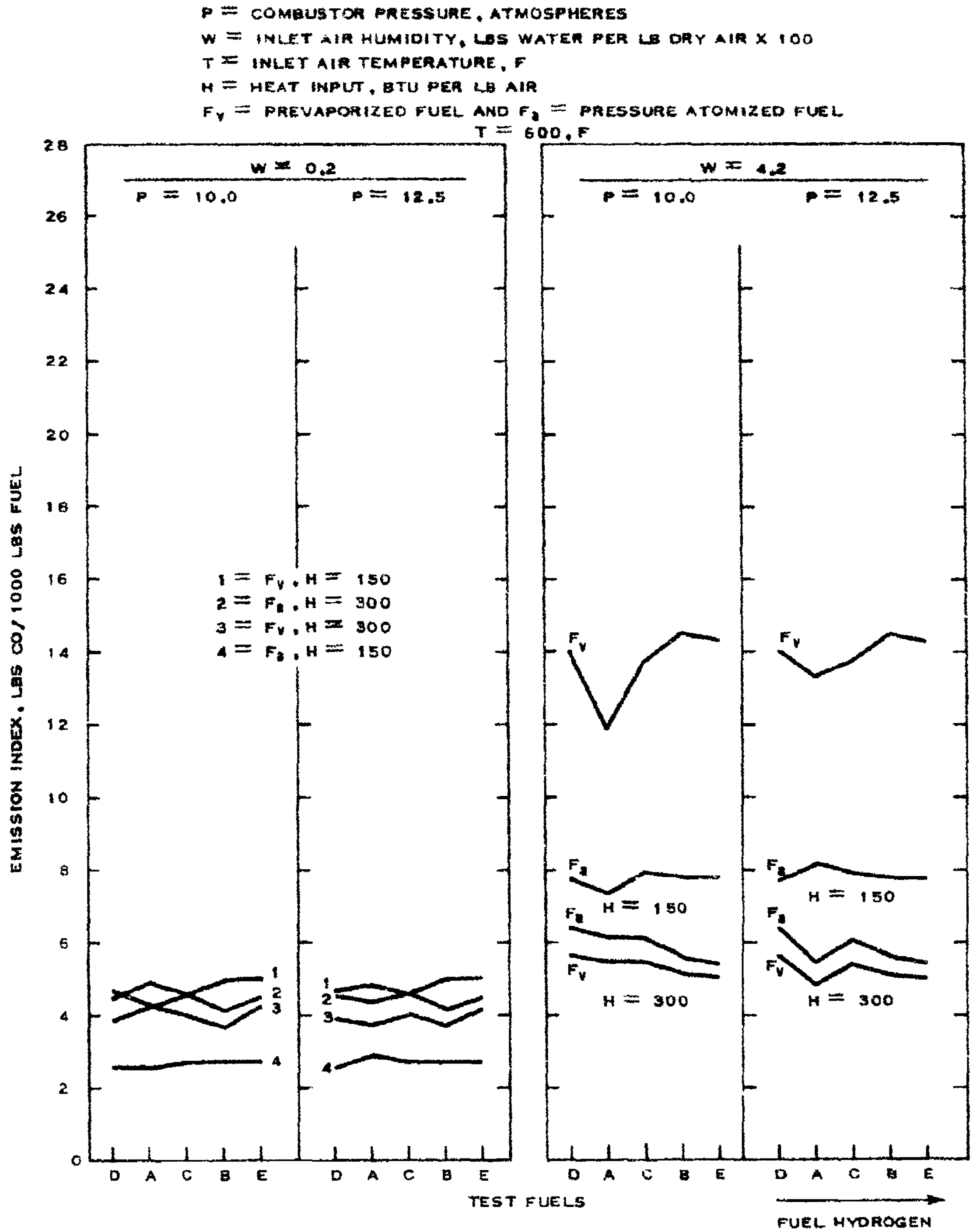

FIGURE 25
CALCULATED CO EMISSIONS WITH FUELS AT SELECTED LEVELS OF OPERATING VARIABLES

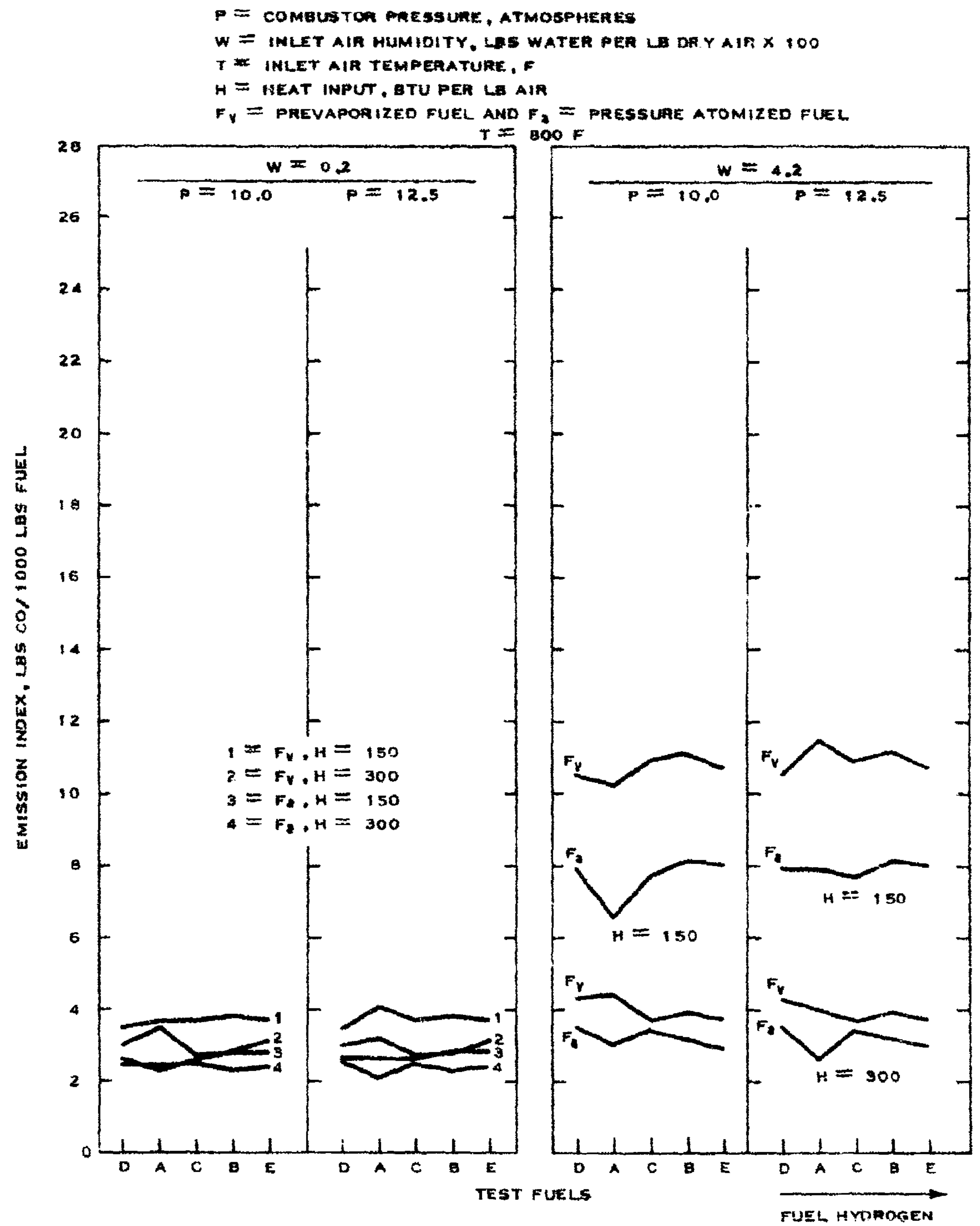

FIGURE 26
CALCULATED CO EMISSIONS WITH FUELS AT SELECTED LEVELS OF OPERATING VARIABLES

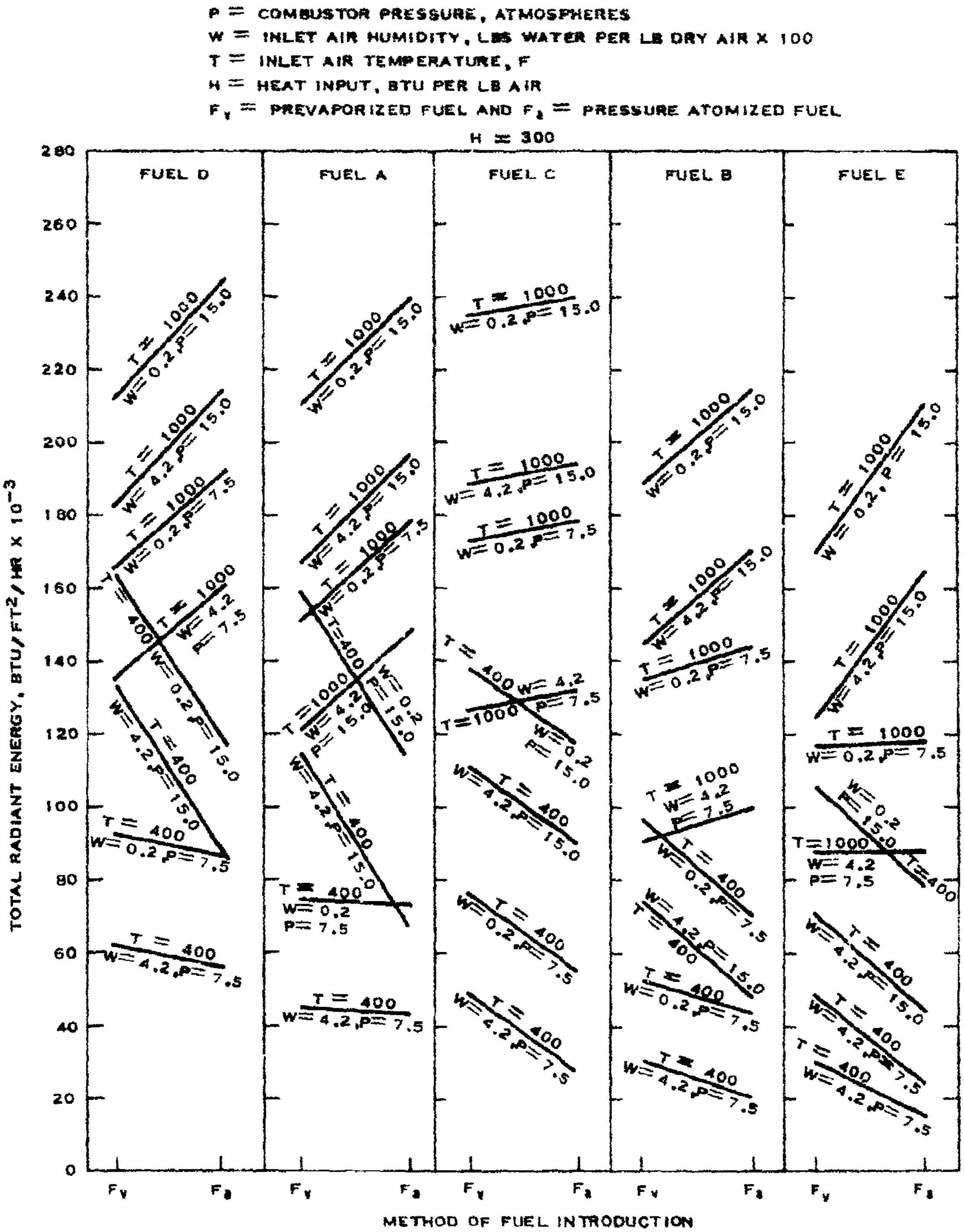

FIGURE 27
CALCULATED RADIANT ENERGY FOR COMPARISONS
OF METHODS OF FUEL INTRODUCTION

P = COMBUSTOR PRESSURE, ATMOSPHERES
W = INLET AIR HUMIDITY, LBS WATER PER LB DRY AIR X 100
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_v = PREVAPORIZED FUEL AND F_a = PRESSURE ATOMIZED FUEL

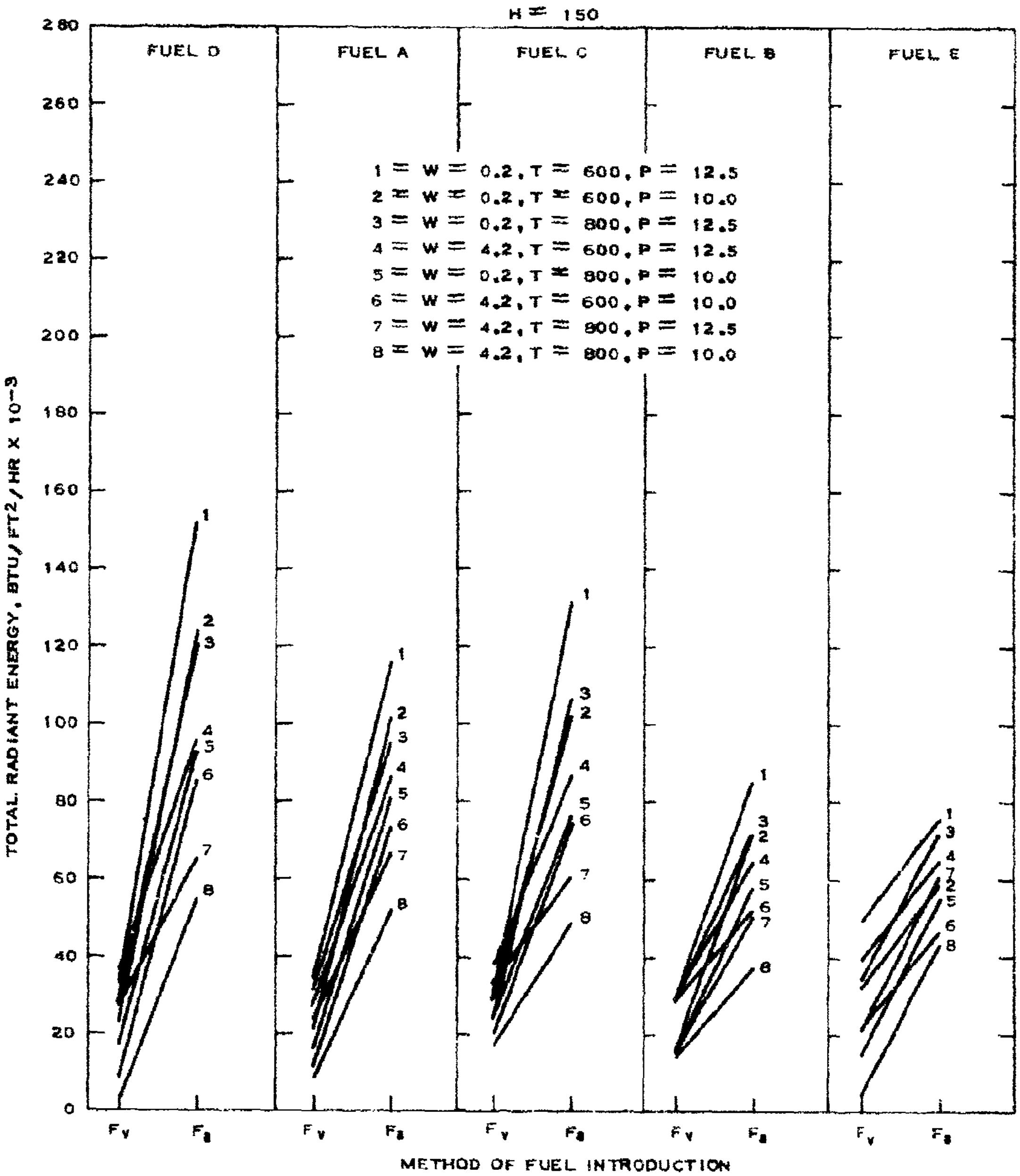

FIGURE 28
CALCULATED RADIANT ENERGY FOR COMPARISONS
OF METHODS OF FUEL INTRODUCTION

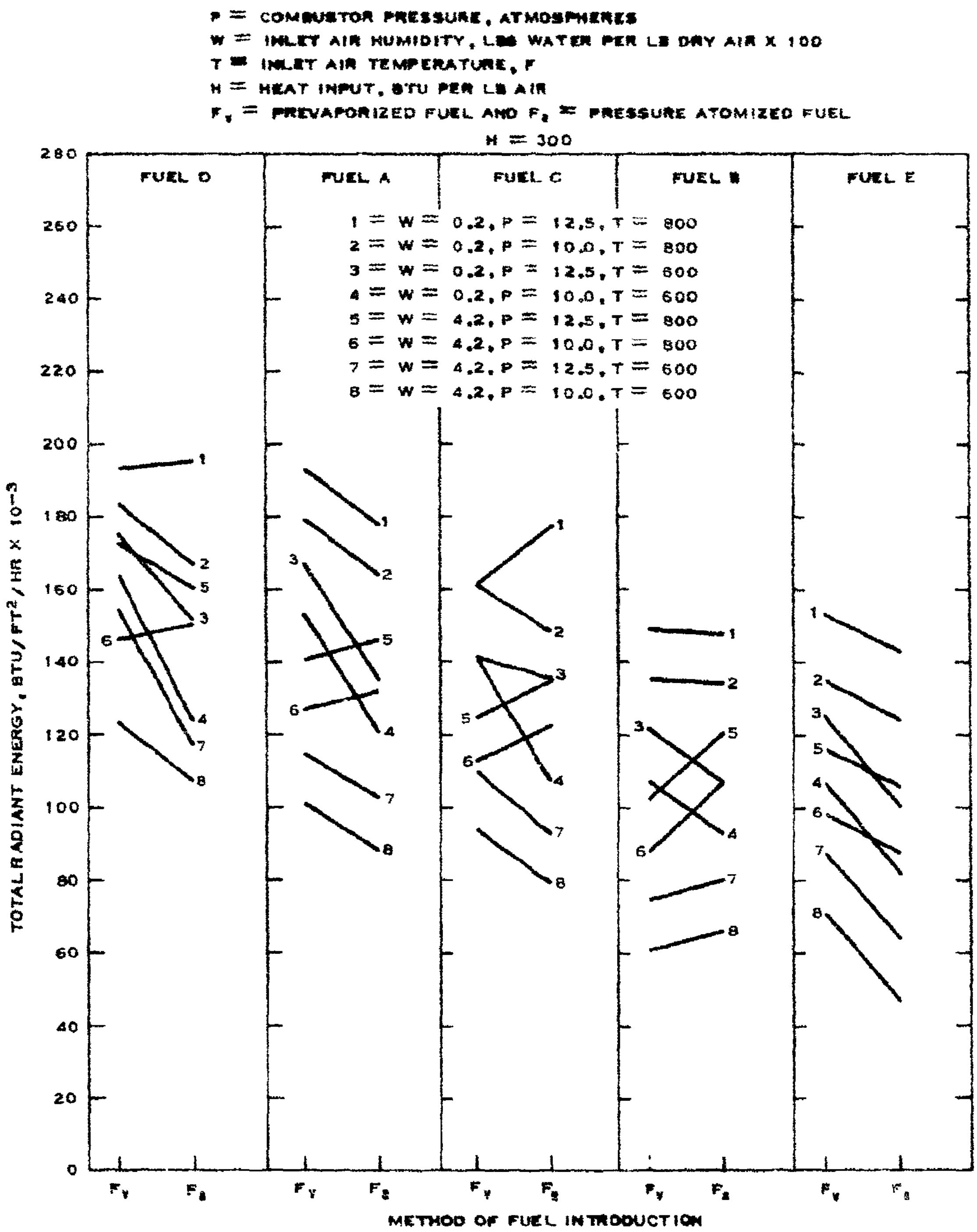

FIGURE 29
CALCULATED RADIANT ENERGY FOR COMPARISONS
OF METHODS OF FUEL INTRODUCTION

P = COMBUSTOR PRESSURE, ATMOSPHERES
W = INLET AIR HUMIDITY, LBS WATER PER LB DRY AIR X 100
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_v = PREVAPORIZED FUEL AND F_a = PRESSURE ATOMIZED FUEL

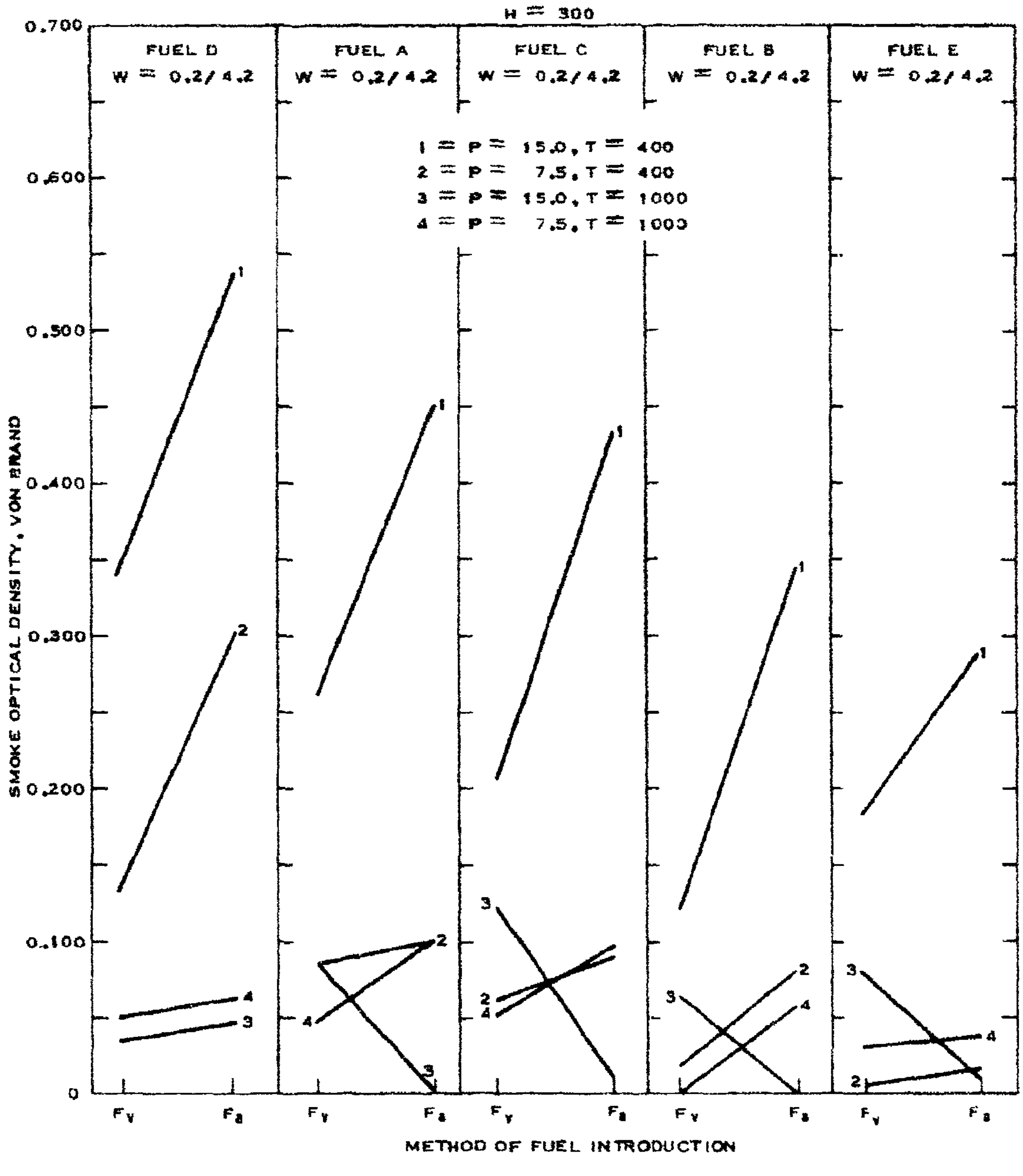

FIGURE 30
CALCULATED SMOKE EMISSIONS FOR COMPARISONS
OF METHODS OF FUEL INTRODUCTION

P = COMBUSTOR PRESSURE, ATMOSPHERES
W = INLET AIR HUMIDITY, LBS WATER PER LB DRY AIR X 100
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_V = PREVAPORIZED FUEL AND F_S = PRESSURE ATOMIZED FUEL

W = 0.2/4.2

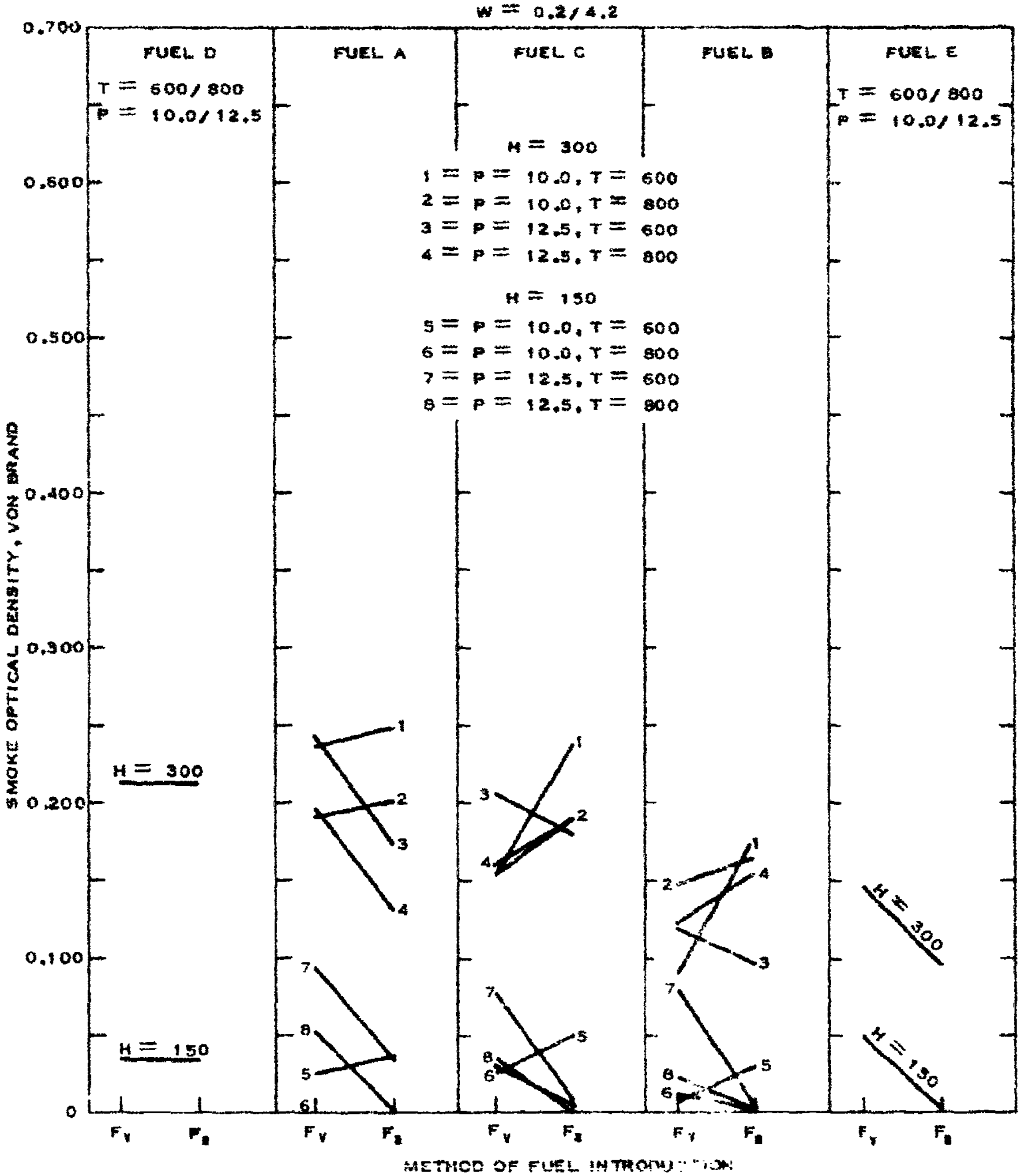

FIGURE 31
CALCULATED SMOKE EMISSIONS FOR COMPARISONS
OF METHODS OF FUEL INTRODUCTION

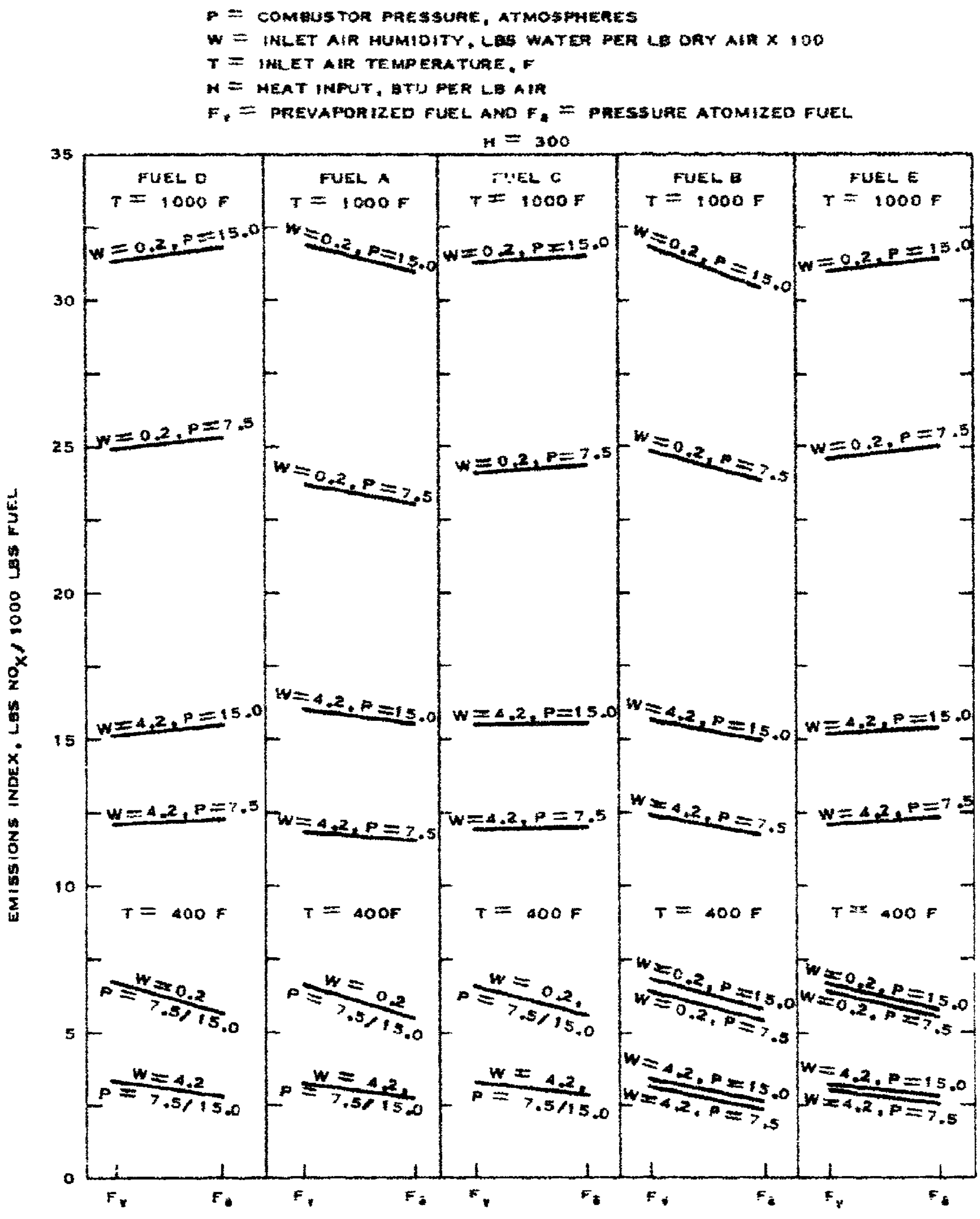

FIGURE 32
CALCULATED NO_X EMISSIONS FOR COMPARISONS OF METHODS OF FUEL INTRODUCTION

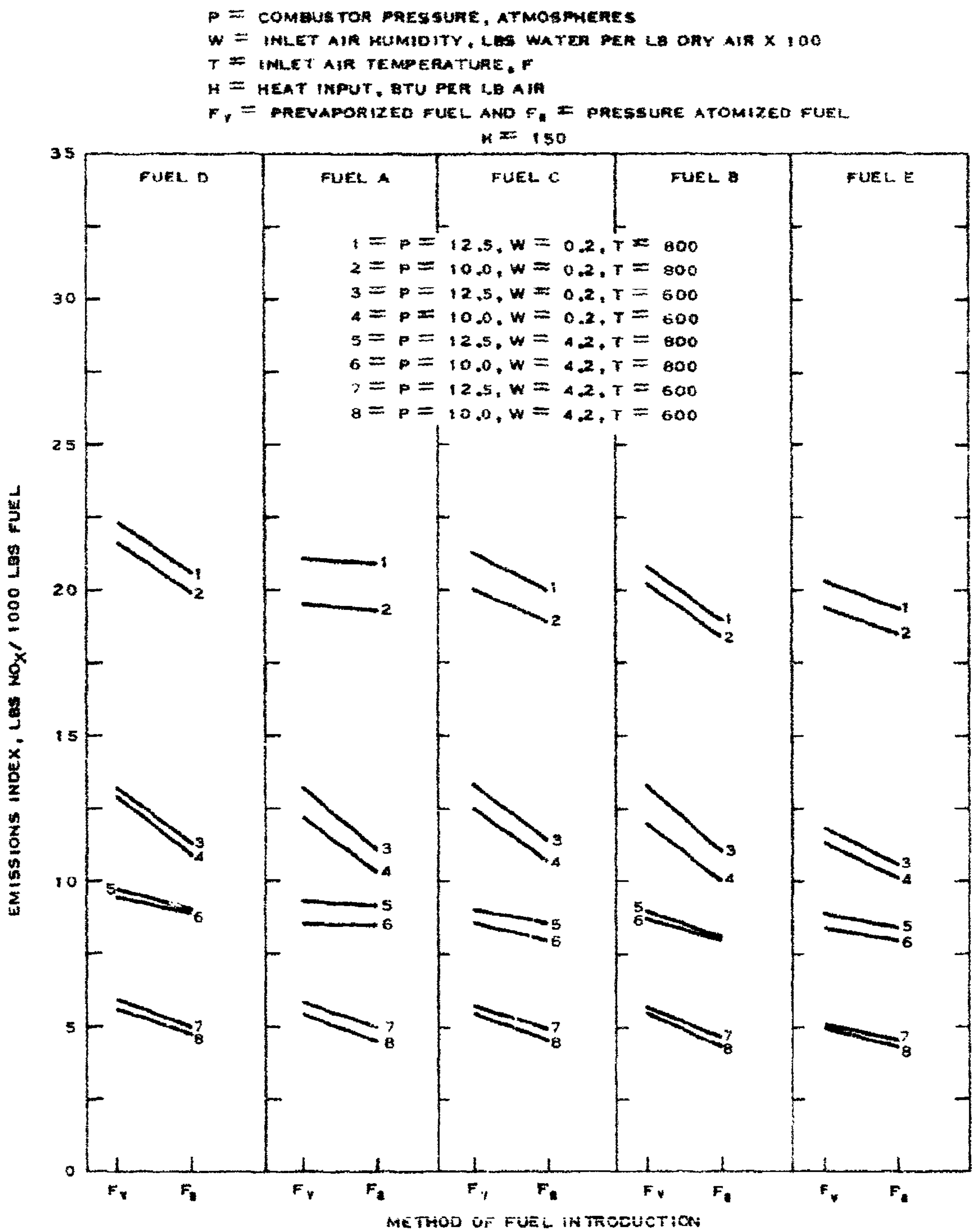

FIGURE 33
CALCULATED NO_X EMISSIONS FOR COMPARISONS OF METHODS OF FUEL INTRODUCTION

P = COMBUSTOR PRESSURE, ATMOSPHERES
W = INLET AIR HUMIDITY, LBS WATER PER LB DRY AIR X 100
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_v = PREVAPORIZED FUEL AND F_a = PRESSURE ATOMIZED FUEL

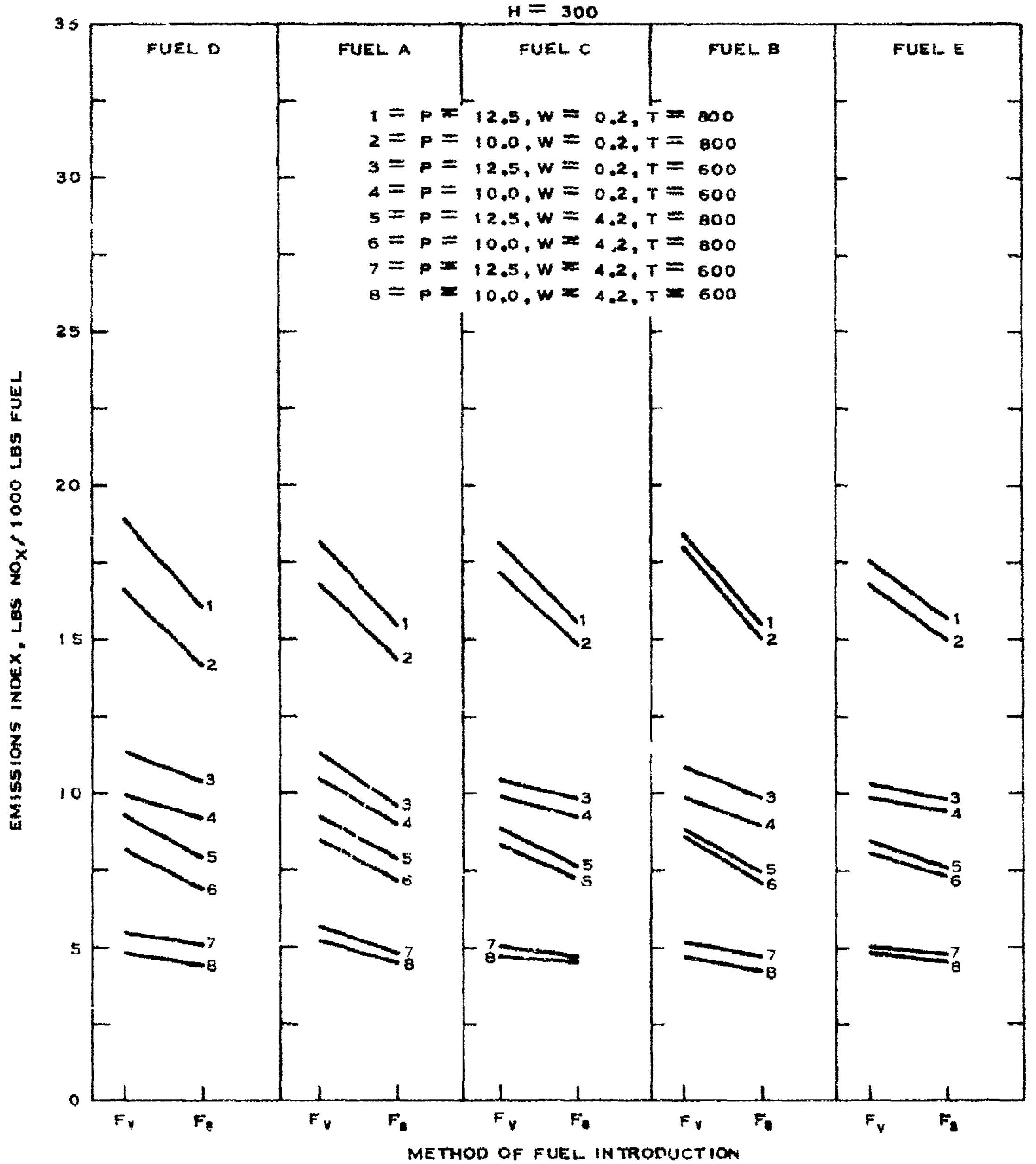

FIGURE 34
CALCULATED NO_X EMISSIONS FOR COMPARISONS OF METHODS OF FUEL INTRODUCTION

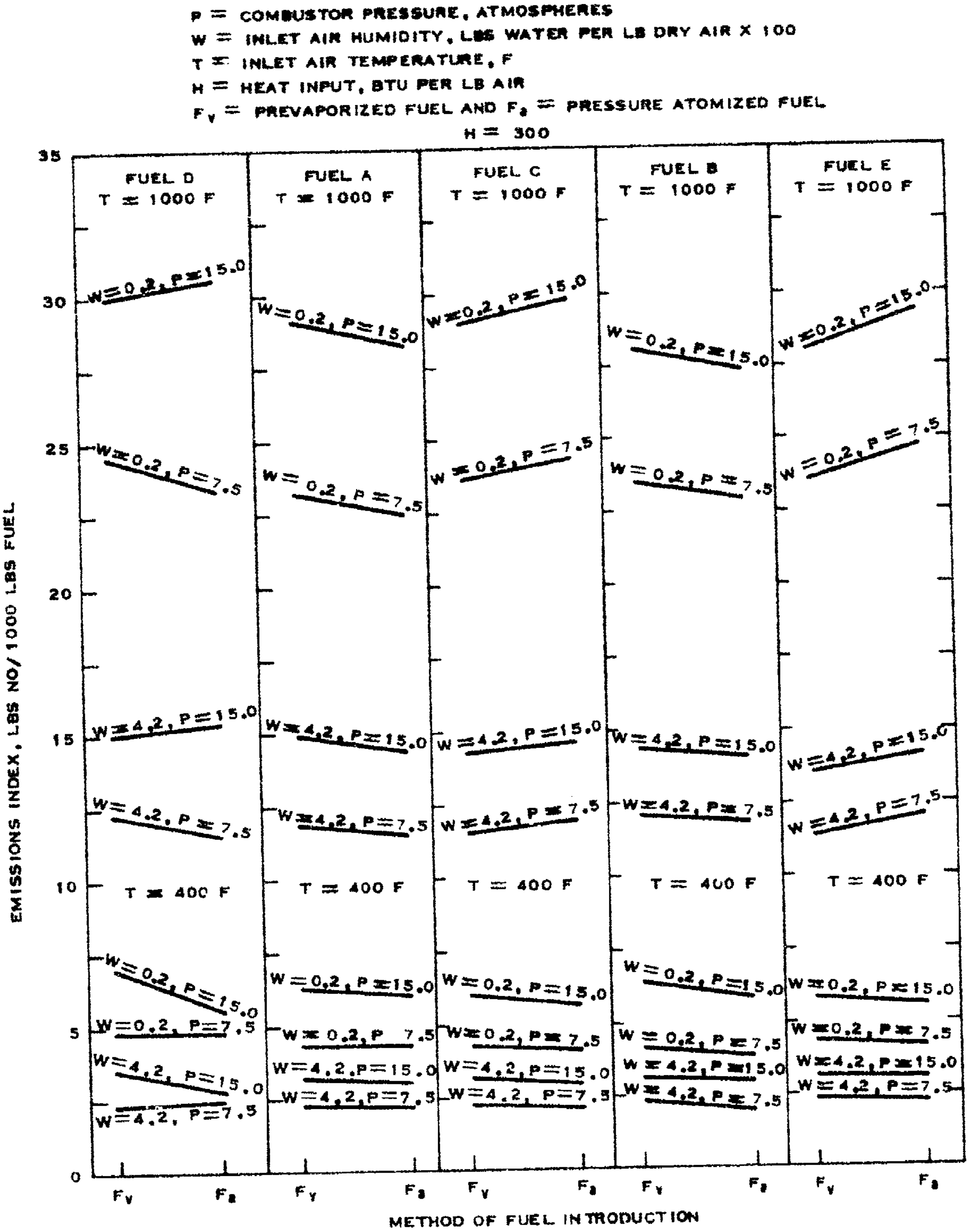

FIGURE 35
CALCULATED CO EMISSIONS FOR COMPARISONS
OF METHODS OF FUEL INTRODUCTION

P = COMBUSTOR PRESSURE, ATMOSPHERES
W = INLET AIR HUMIDITY, LBS WATER PER LB DRY AIR X 100
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_v = PREVAPORIZED FUEL AND F_a = PRESSURE ATOMIZED FUEL

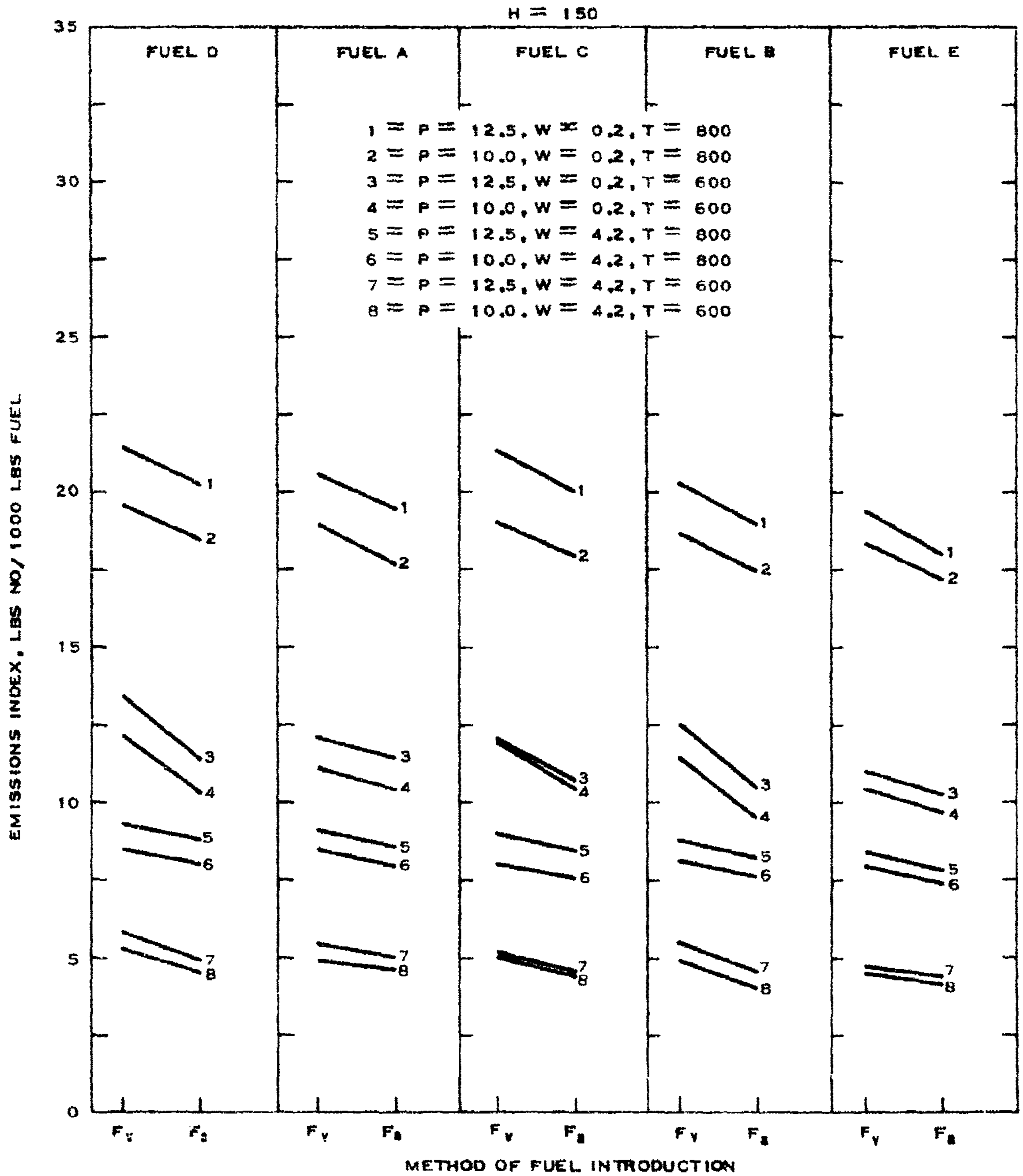

FIGURE 36
CALCULATED NO EMISSIONS FOR COMPARISONS
OF METHODS OF FUEL INTRODUCTION

P = COMBUSTOR PRESSURE, ATMOSPHERES
W = INLET AIR HUMIDITY, LBS WATER PER LB DRY AIR X 100
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_v = PREVAPORIZED FUEL AND F_a = PRESSURE ATOMIZED FUEL

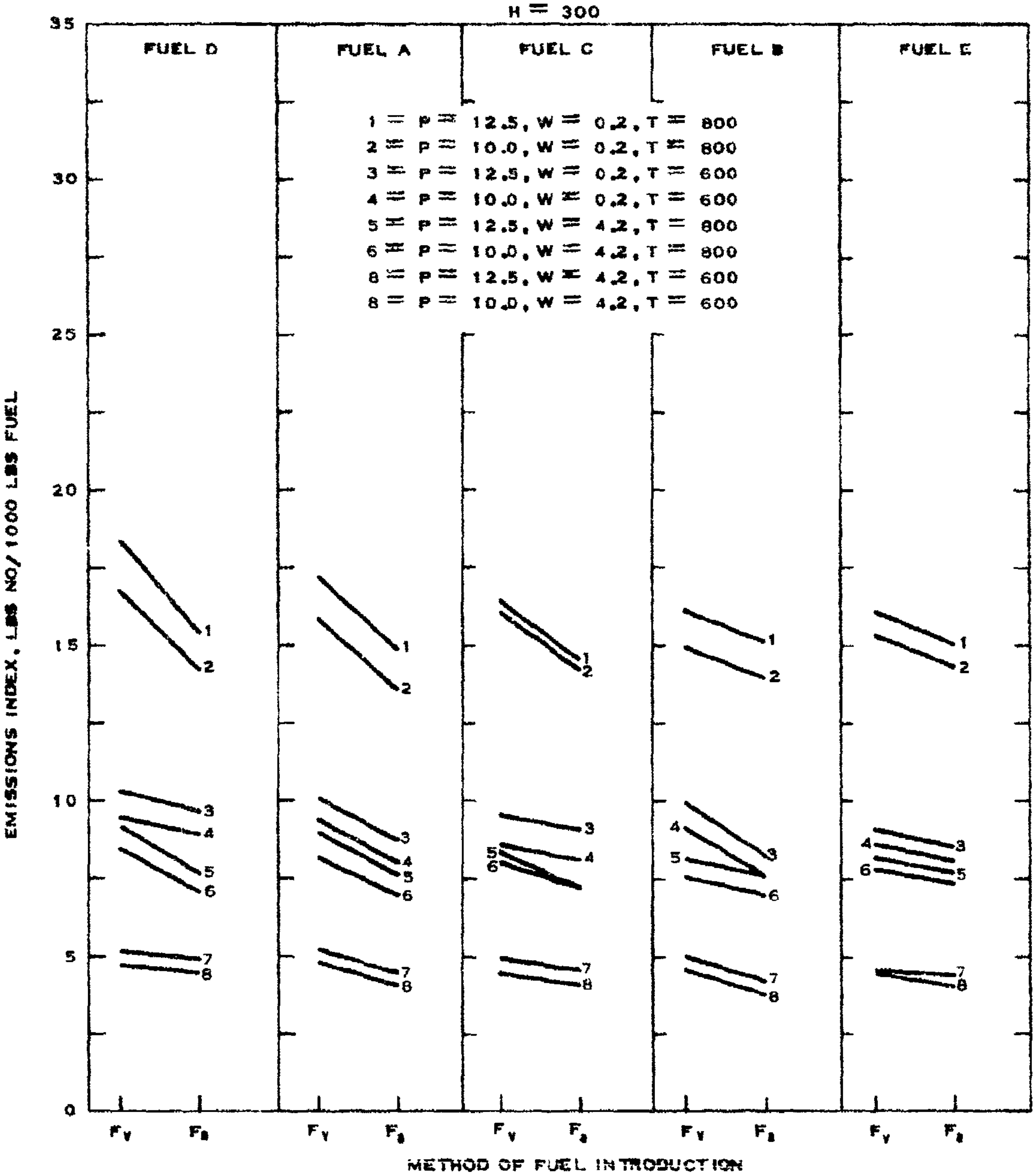

FIGURE 37
CALCULATED NO EMISSIONS FOR COMPARISONS
OF METHODS OF FUEL INTRODUCTION

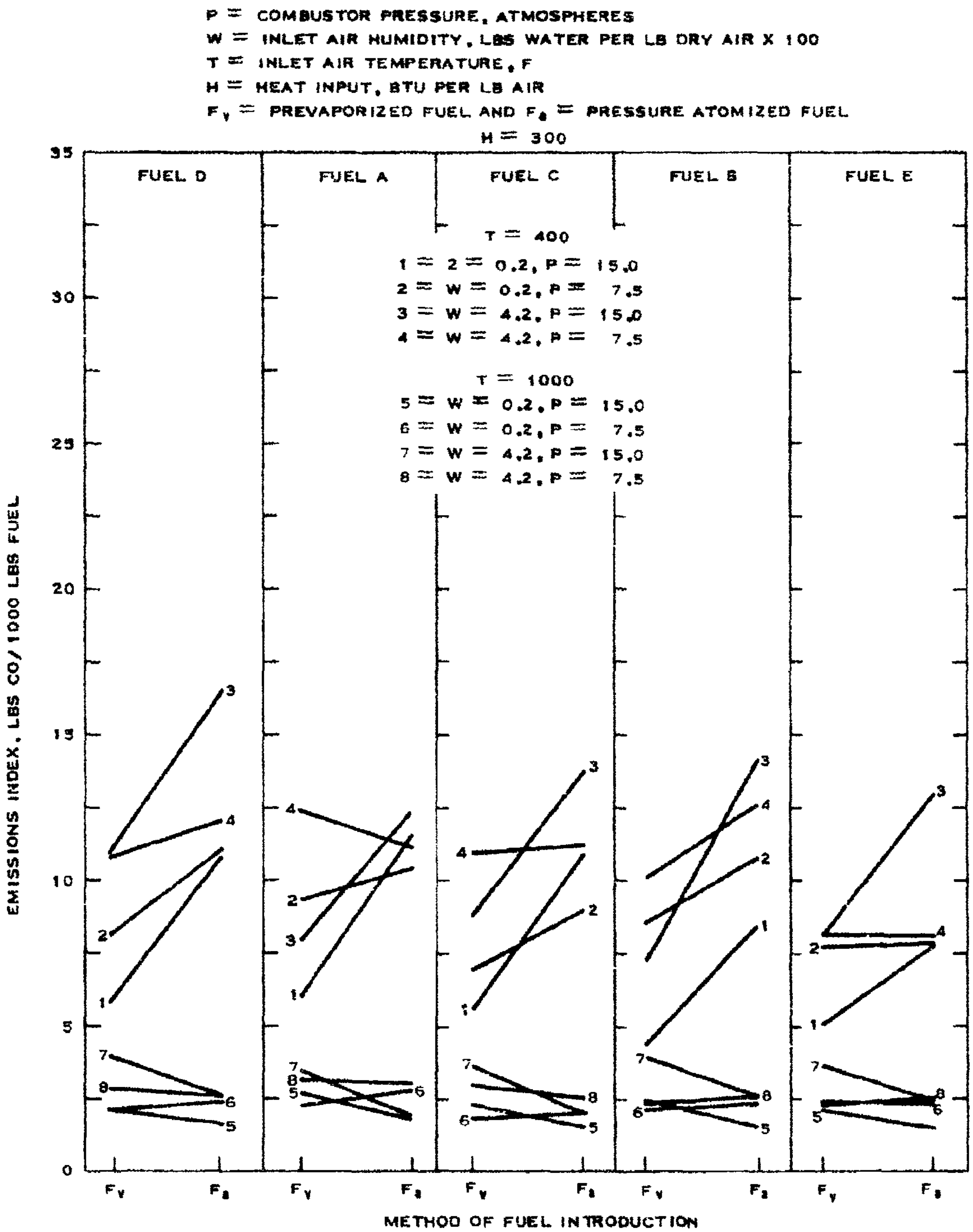

FIGURE 38
CALCULATED CO EMISSIONS FOR COMPARISONS OF METHODS OF FUEL INTRODUCTION

P = COMBUSTOR PRESSURE, ATMOSPHERES
W = INLET AIR HUMIDITY, LBS WATER PER LB DRY AIR X 100
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_v = PREVAPORIZED FUEL AND F_a = PRESSURE ATOMIZED FUEL

H = 150

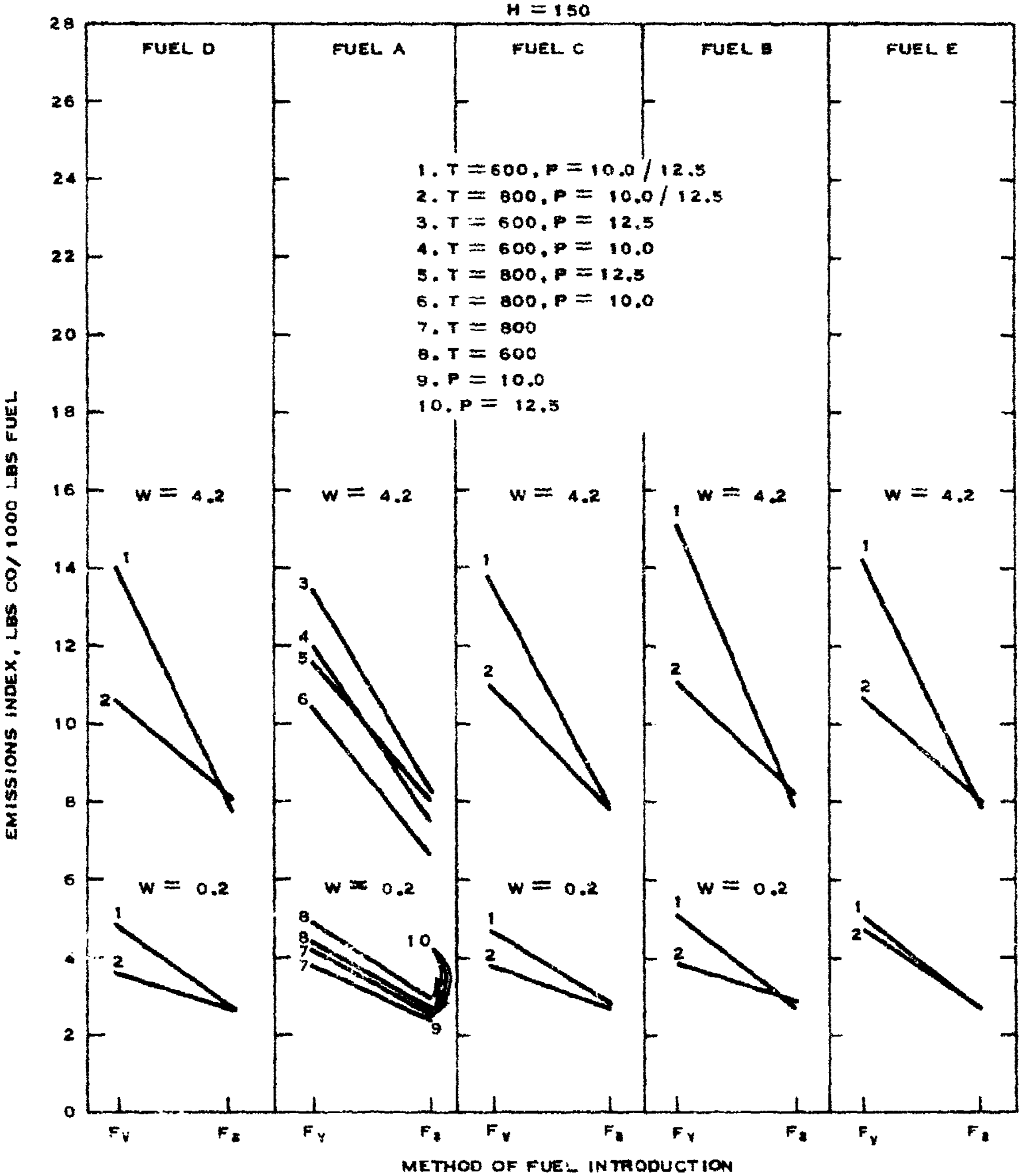

FIGURE 39
CALCULATED CO EMISSIONS FOR COMPARISONS OF METHODS OF FUEL INTRODUCTION

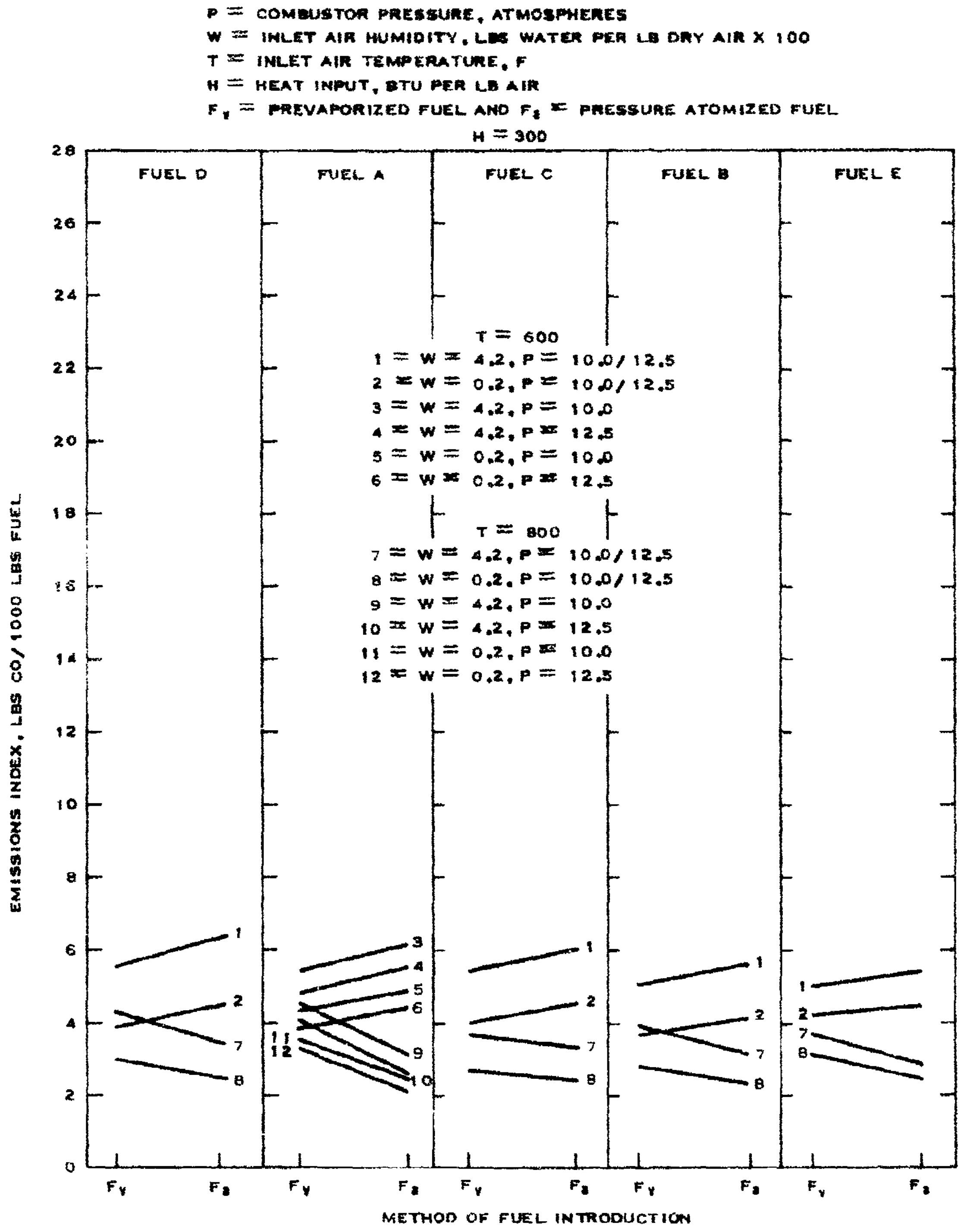

FIGURE 40
CALCULATED CO EMISSIONS FOR COMPARISONS OF METHODS OF FUEL INTRODUCTION

P = COMBUSTOR PRESSURE, ATMOSPHERES
EI = EMISSION INDEX, LBS POLLUTANT PER 1000LBS FUEL
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_v = PREVAPORIZED FUEL AND F_s = PRESSURE ATOMIZED FUEL
H = 300

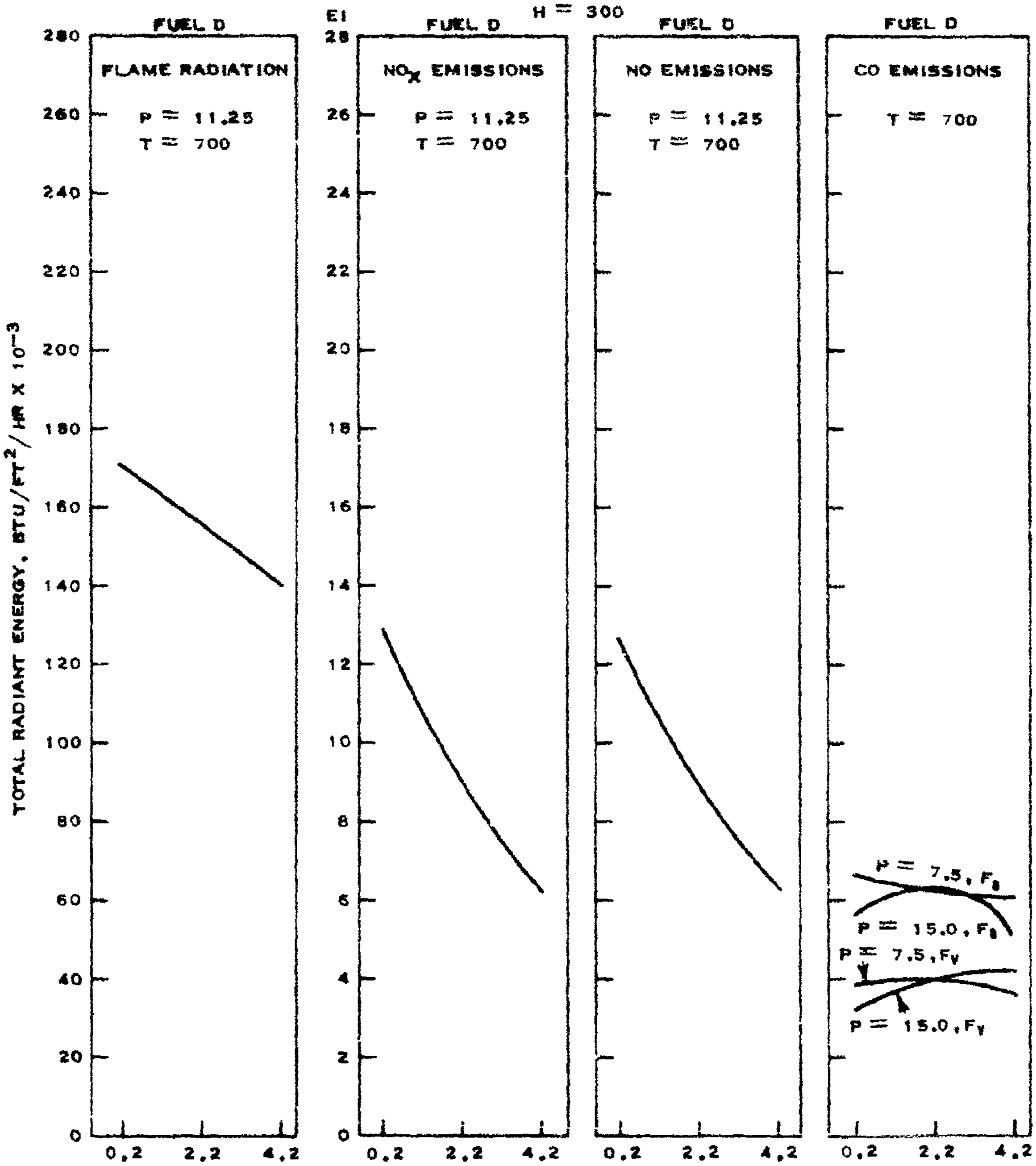

FIGURE 41
CALCULATED EMISSIONS FOR COMPARISONS
OF EFFECTS OF INLET AIR HUMIDITY

P = COMBUSTOR PRESSURE, ATMOSPHERES
EI = EMISSION INDEX, LBS POLLUTANT PER 1000 LBS FUEL
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_v = PREVAPORIZED FUEL AND F_a = PRESSURE ATOMIZED FUEL

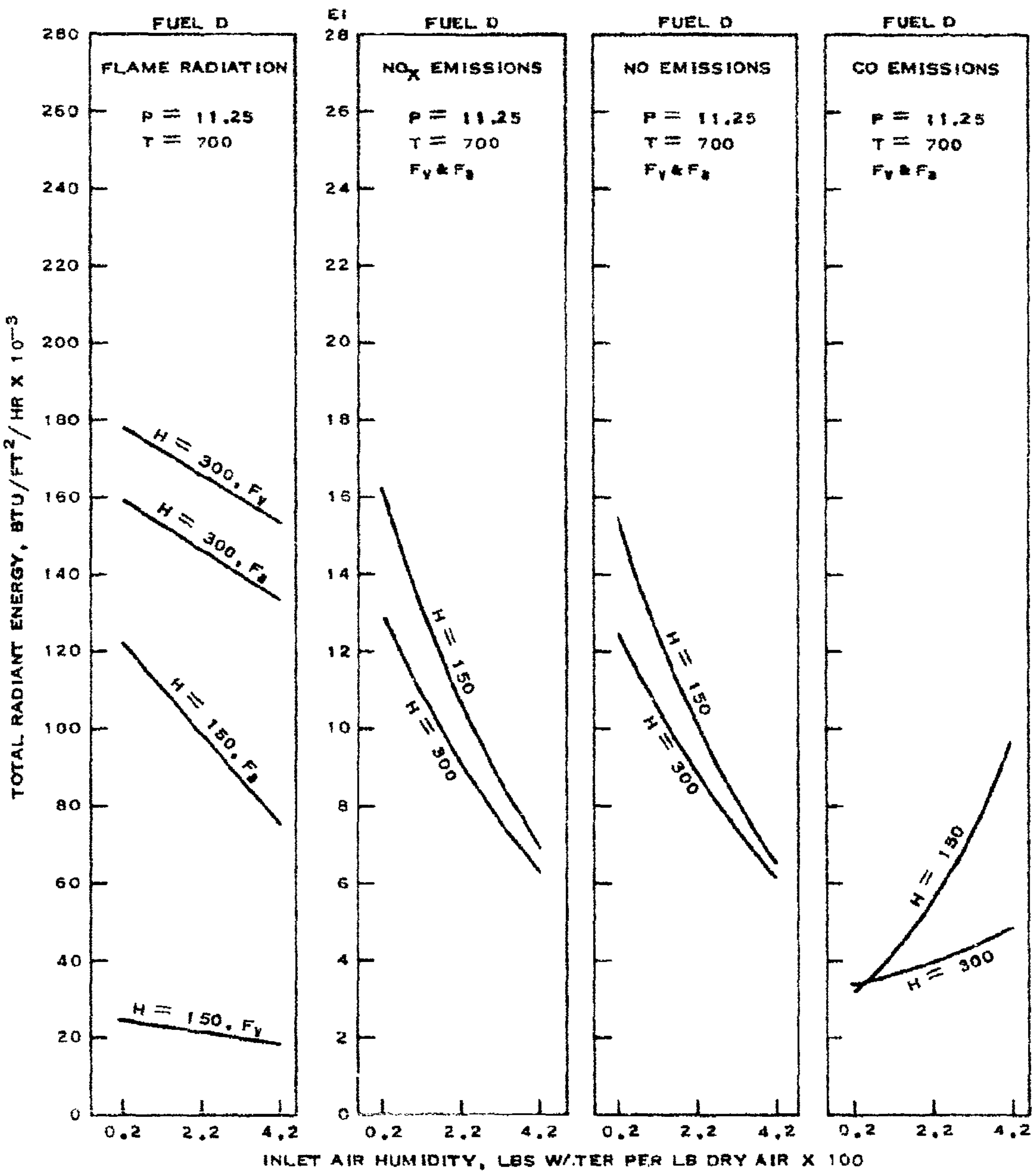

FIGURE 42
CALCULATED EMISSIONS FOR COMPARISONS
OF EFFECTS OF INLET AIR HUMIDITY

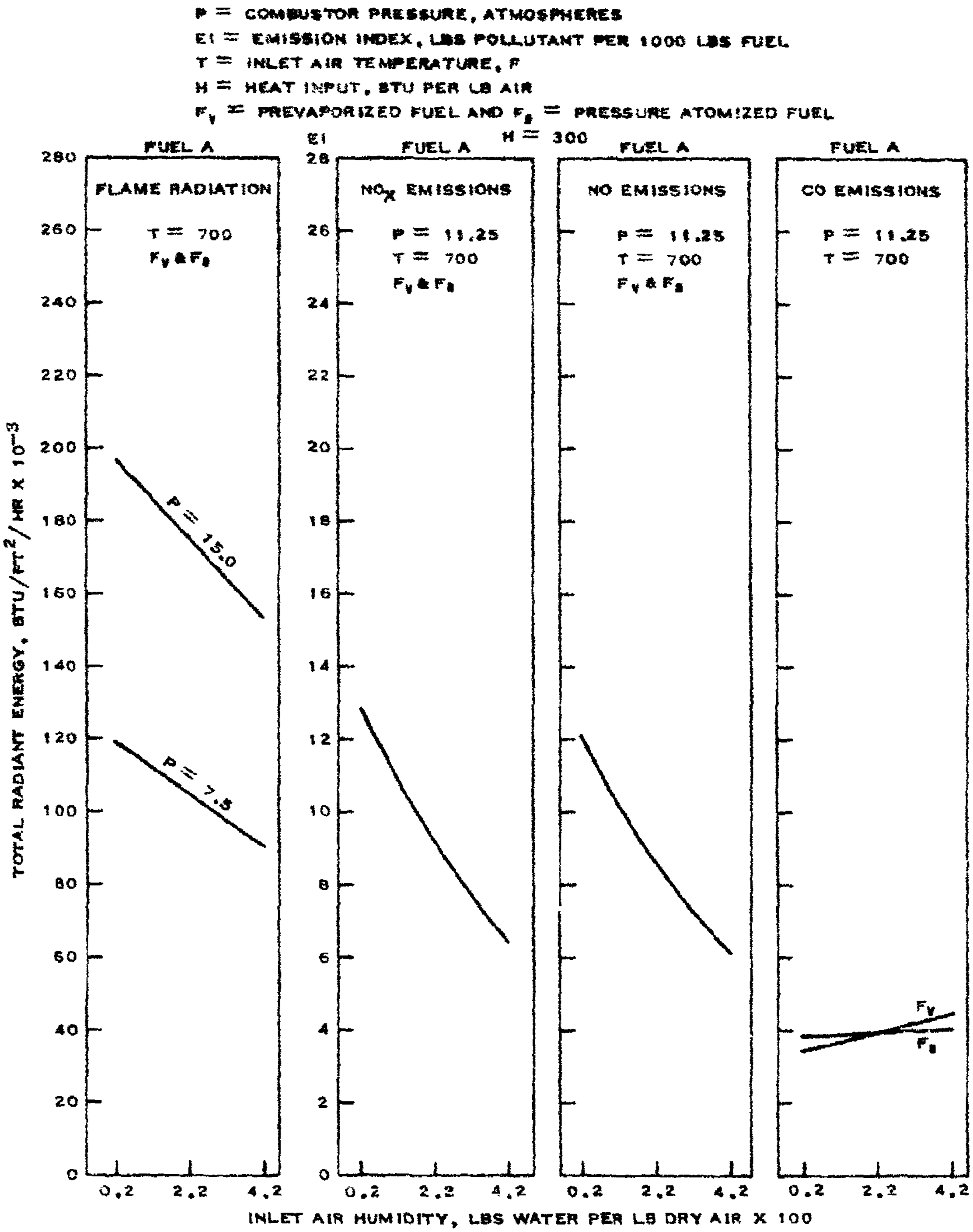

FIGURE 43
CALCULATED EMISSIONS FOR COMPARISONS
OF EFFECTS OF INLET AIR HUMIDITY

P = COMBUSTOR PRESSURE, ATMOSPHERES
EI = EMISSION INDEX, LBS POLLUTANT PER 1000 LBS FUEL
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_v = PREVAPORIZED FUEL AND F_a = PRESSURE ATOMIZED FUEL

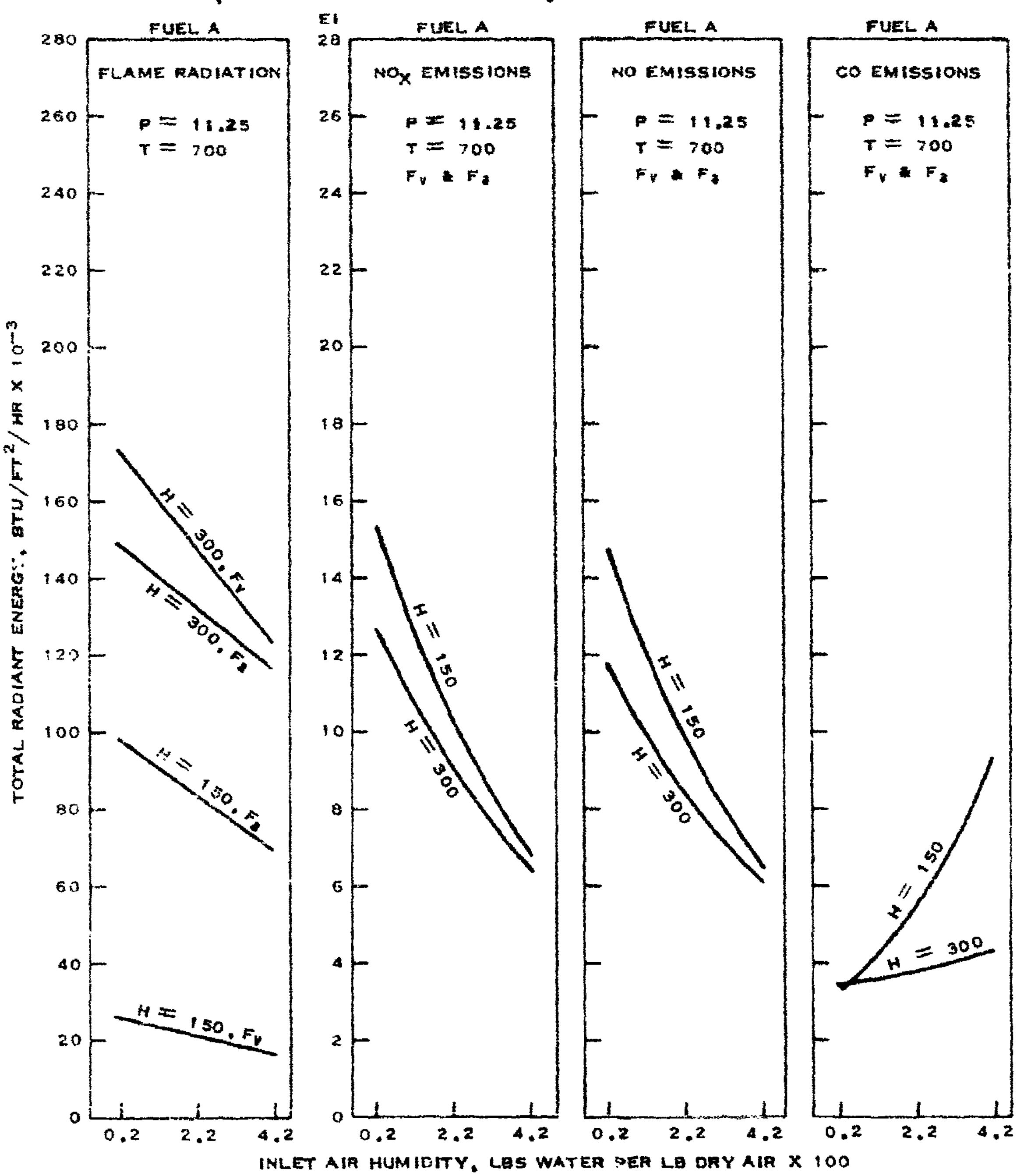

FIGURE 44
CALCULATED EMISSIONS FOR COMPARISONS
OF EFFECTS OF INLET AIR HUMIDITY

P = COMBUSTOR PRESSURE, ATMOSPHERES
EI = EMISSION INDEX, LBS POLLUTANT PER 1000 LBS FUEL
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_v = PREVAPORIZED FUEL AND F_s = PRESSURE ATOMIZED FUEL

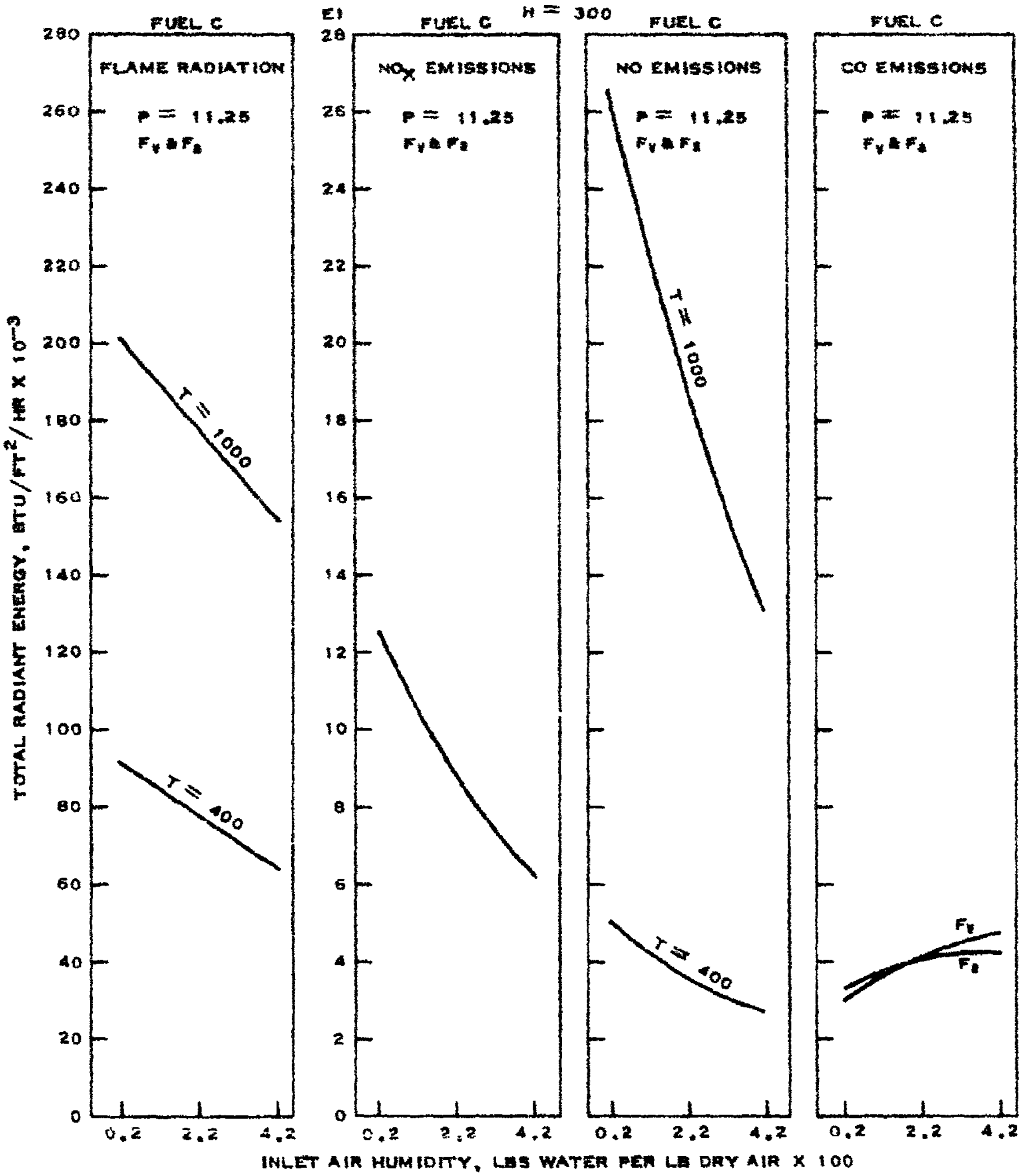

FIGURE 45
CALCULATED EMISSIONS FOR COMPARISONS
OF EFFECTS OF INLET AIR HUMIDITY

P = COMBUSTOR PRESSURE, ATMOSPHERES
EI = EMISSION INDEX, LBS POLLUTANT PER 1000 LBS FUEL
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_v = PREVAPORIZED FUEL AND F_s = PRESSURE ATOMIZED FUEL

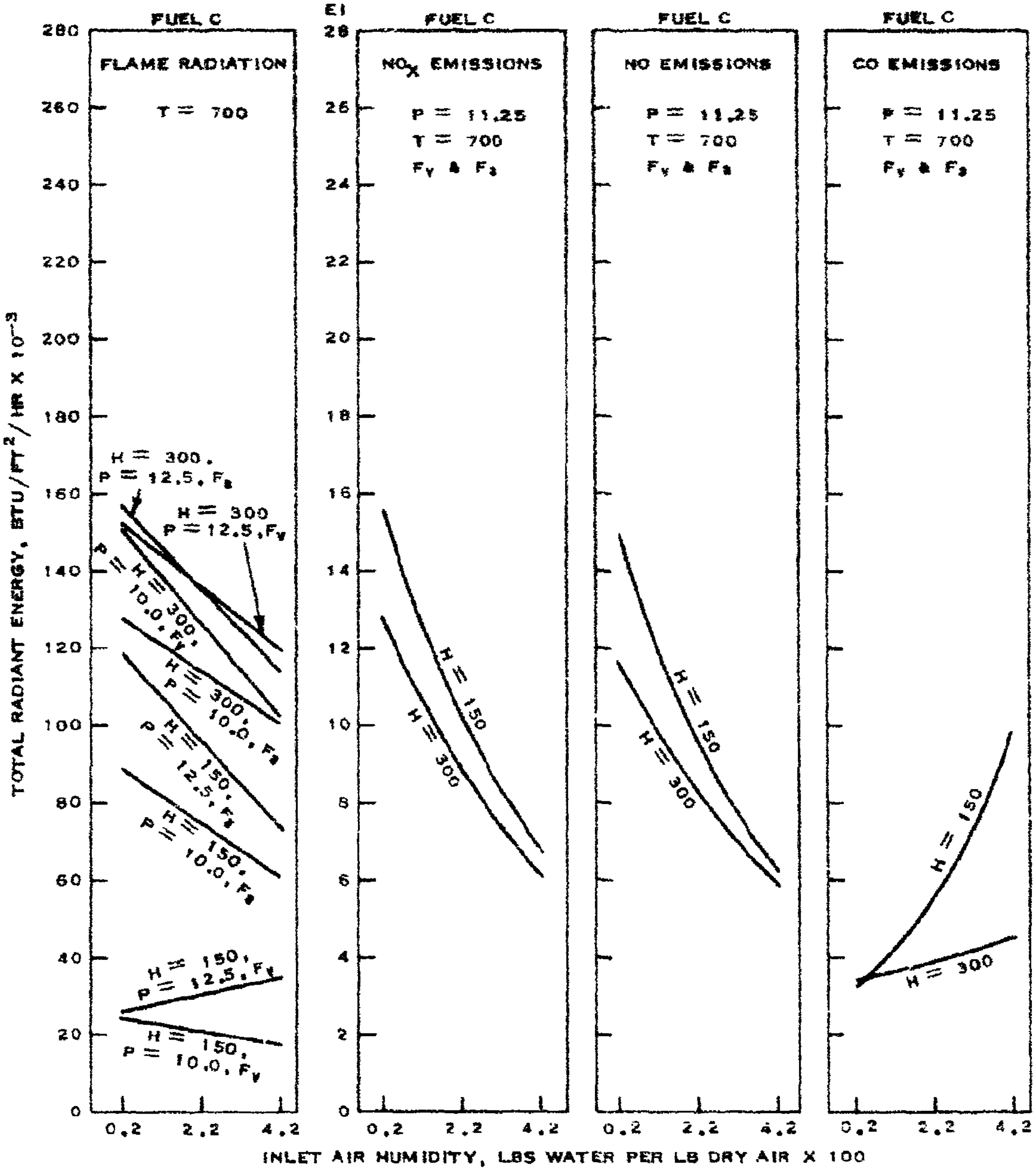

FIGURE 46
CALCULATED EMISSIONS FOR COMPARISONS
OF EFFECTS OF INLET AIR HUMIDITY

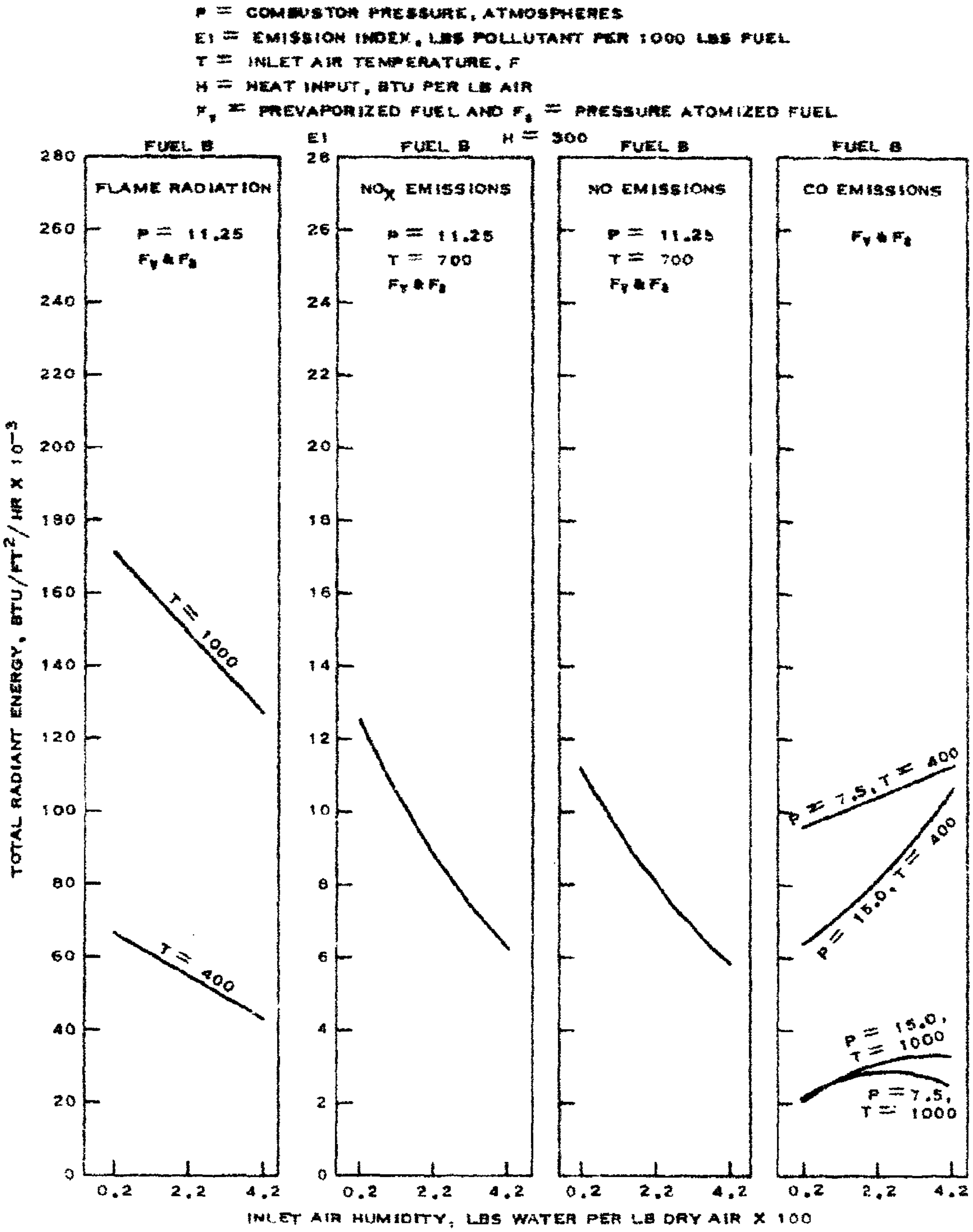

FIGURE 47
CALCULATED EMISSIONS FOR COMPARISONS OF EFFECTS OF INLET AIR HUMIDITY

P = COMBUSTOR PRESSURE, ATMOSPHERES
EI = EMISSION INDEX, LBS POLLUTANT PER 1000 LBS FUEL
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_v = PREVAPORIZED FUEL AND F_a = PRESSURE ATOMIZED FUEL

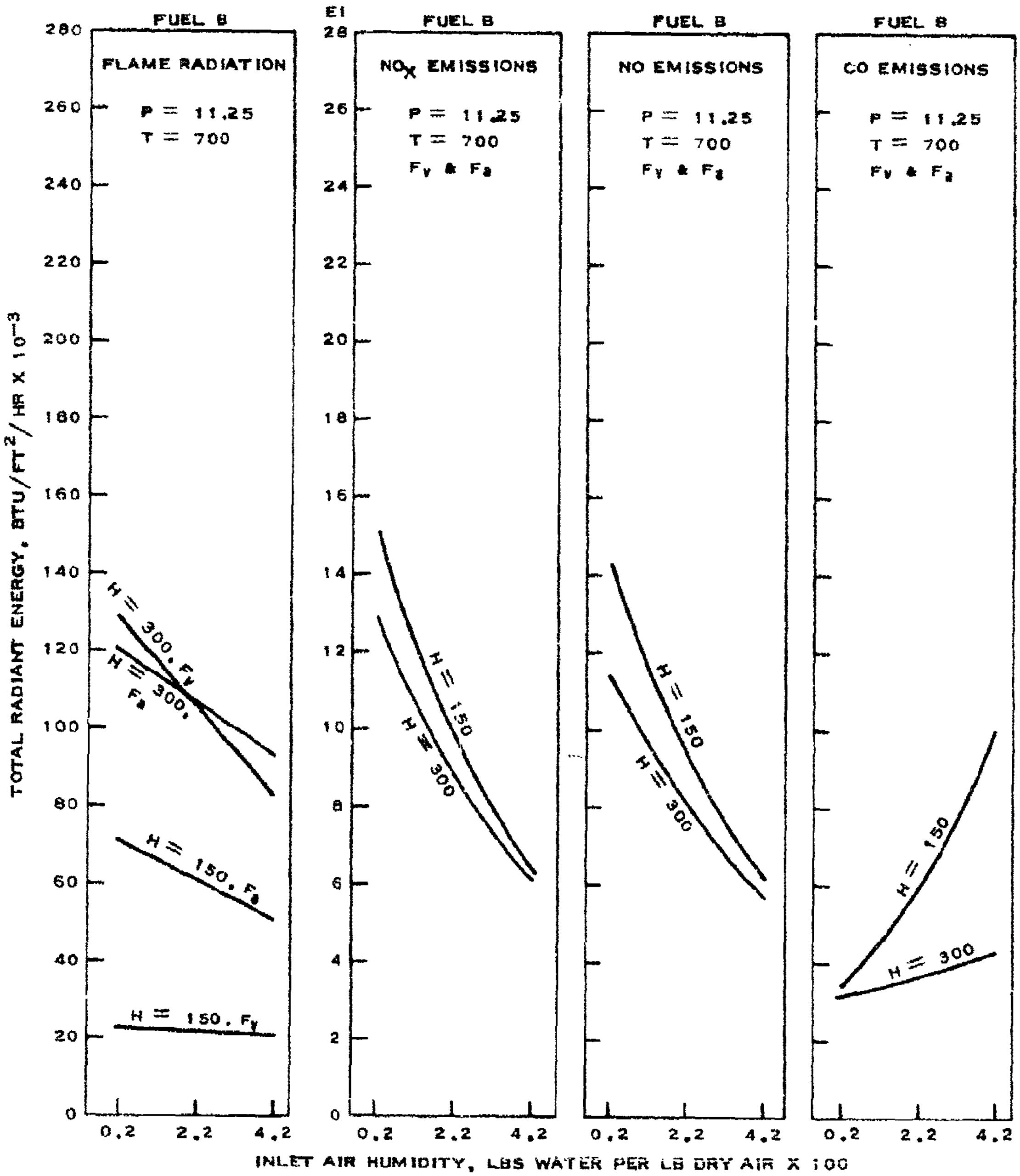

FIGURE 48
CALCULATED EMISSIONS FOR COMPARISONS
OF EFFECTS OF INLET AIR HUMIDITY

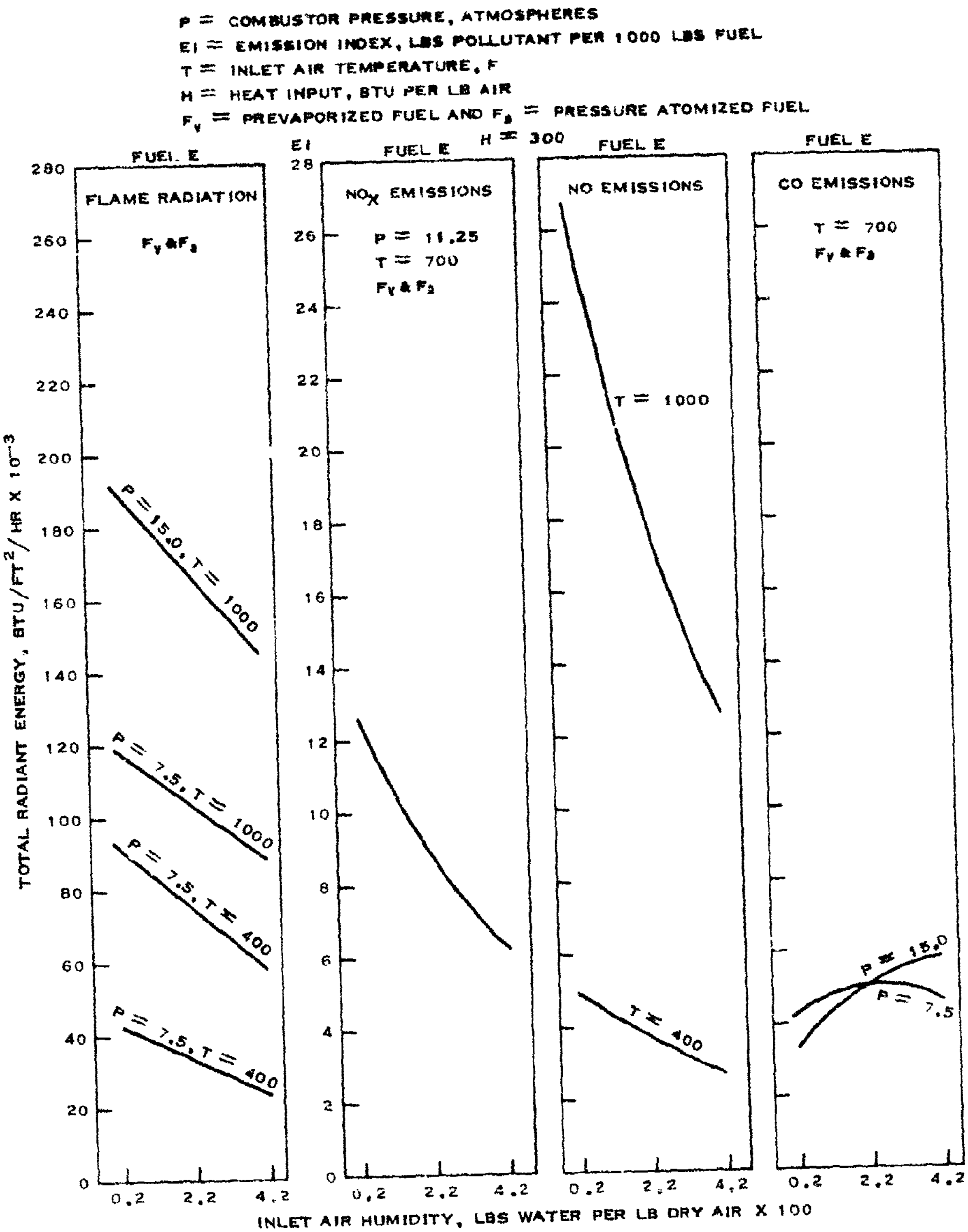

FIGURE 49
CALCULATED EMISSIONS FOR COMPARISONS
OF EFFECTS OF INLET AIR HUMIDITY

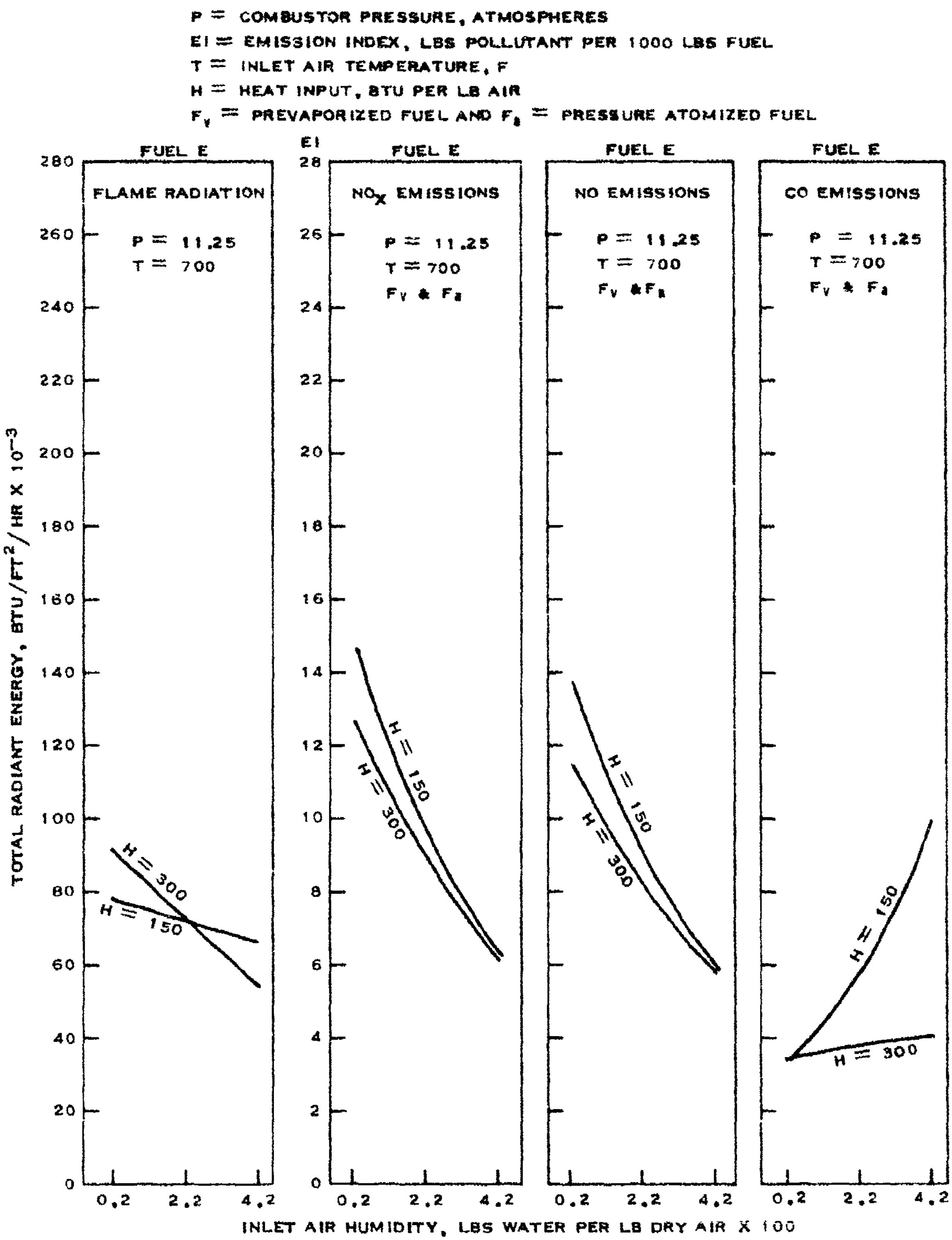

FIGURE 50
CALCULATED EMISSIONS FOR COMPARISONS
OF EFFECTS OF INLET AIR HUMIDITY

P = COMBUSTOR PRESSURE, ATMOSPHERES
W = INLET AIR HUMIDITY, LBS WATER PER LB DRY AIR X 100
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_v = PREVAPORIZED FUEL AND F_a = PRESSURE ATOMIZED FUEL
FUEL A, H = 300

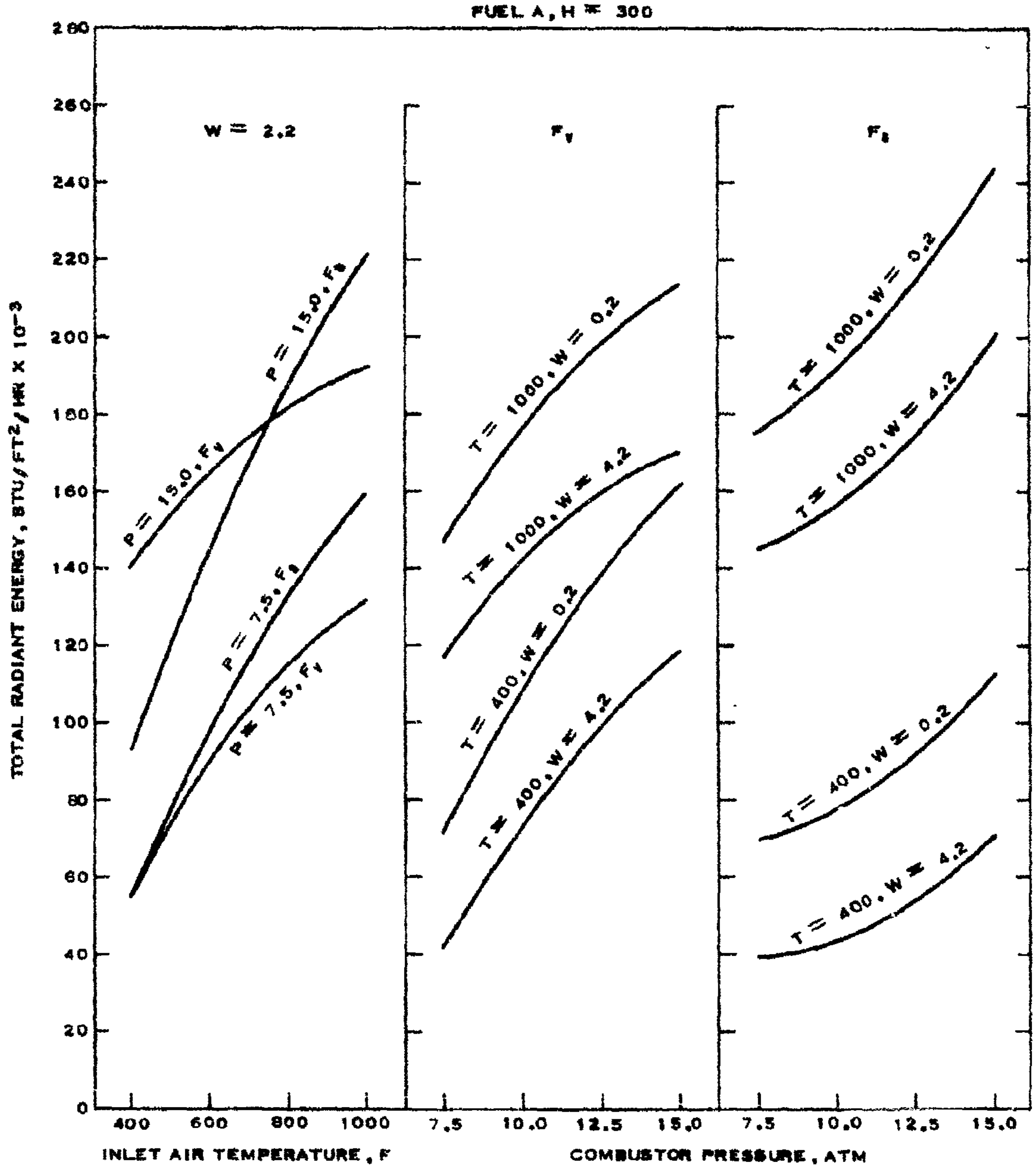

FIGURE 51
CALCULATED EMISSIONS FOR COMPARISONS
OF EFFECTS OF TEMPERATURE AND PRESSURE

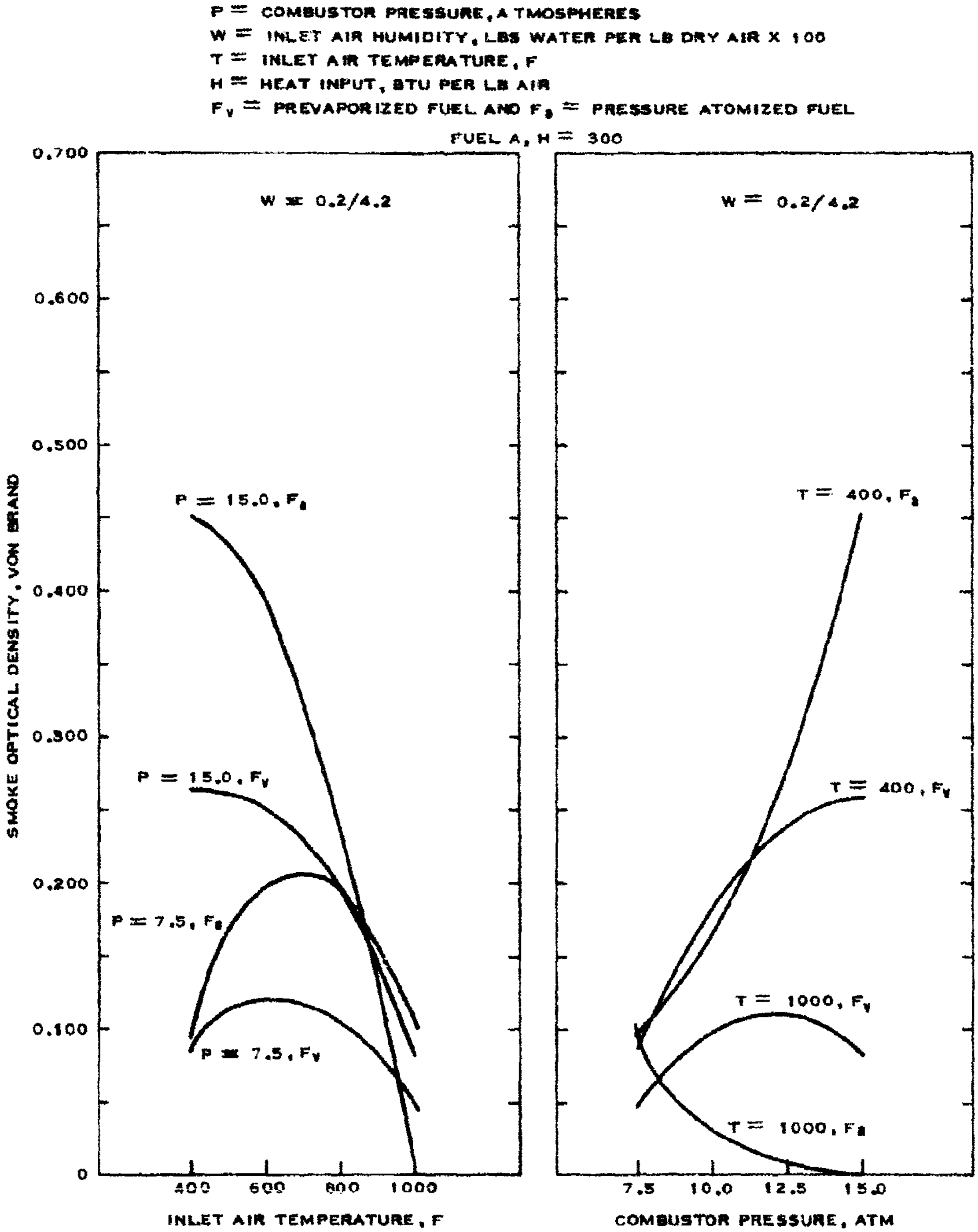

FIGURE 52
CALCULATED SMOKE EMISSIONS AT SELECTED LEVELS OF TEMPERATURE AND PRESSURE

P = COMBUSTOR PRESSURE, ATMOSPHERES
W = INLET AIR HUMIDITY, LBS WATER PER LB DRY AIR X 100
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_V = PREVAPORIZED FUEL AND F_S = PRESSURE ATOMIZED FUEL

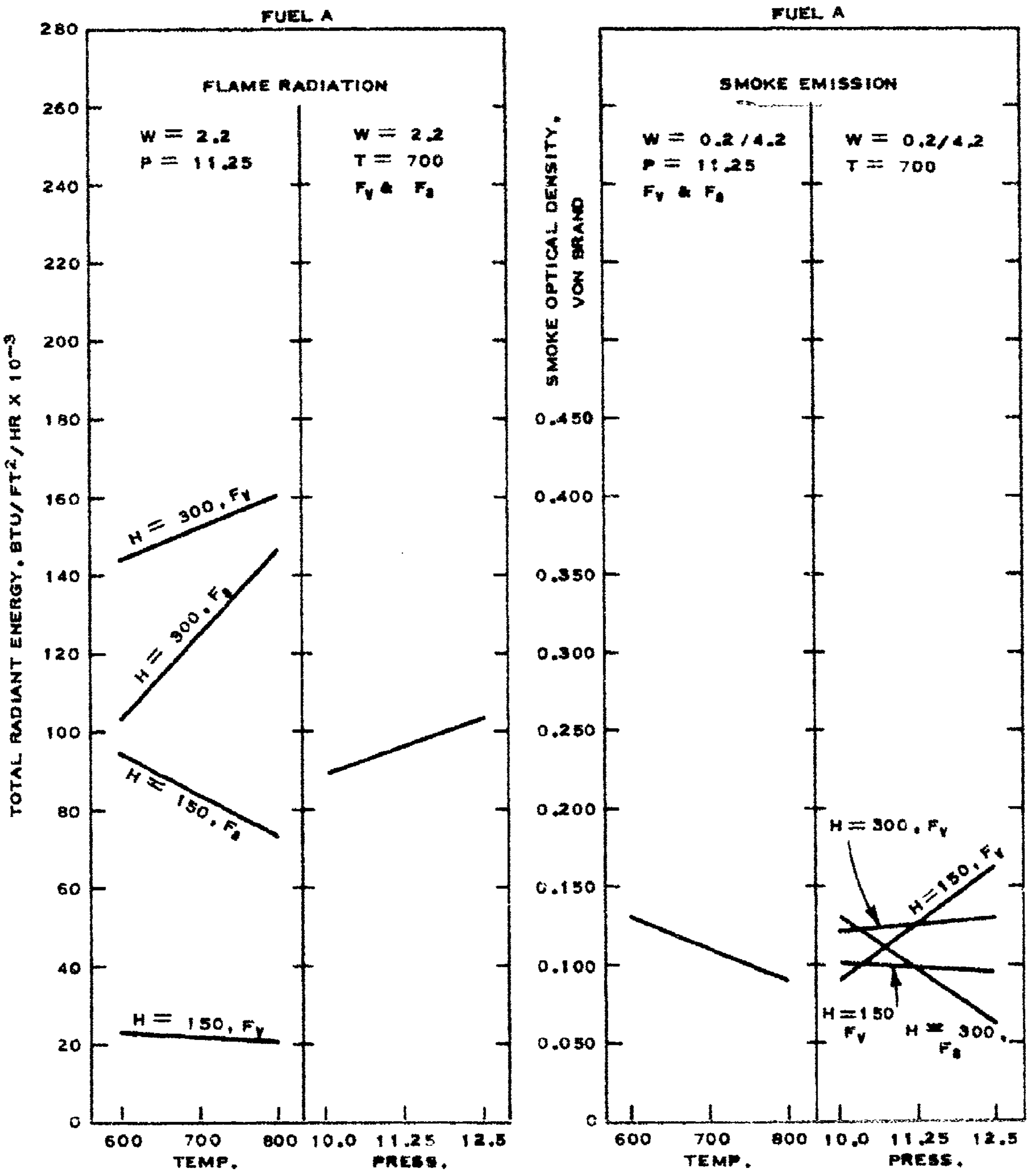

FIGURE 53
CALCULATED EMISSIONS FOR COMPARISONS
OF EFFECTS OF TEMPERATURE AND PRESSURE

P = COMBUSTOR PRESSURE, ATMOSPHERES
W = INLET AIR HUMIDITY, LBS WATER PER LB DRY AIR X 100
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_V = PREVAPORIZED FUEL AND F_a = PRESSURE ATOMIZED FUEL

FUEL A, H = 300

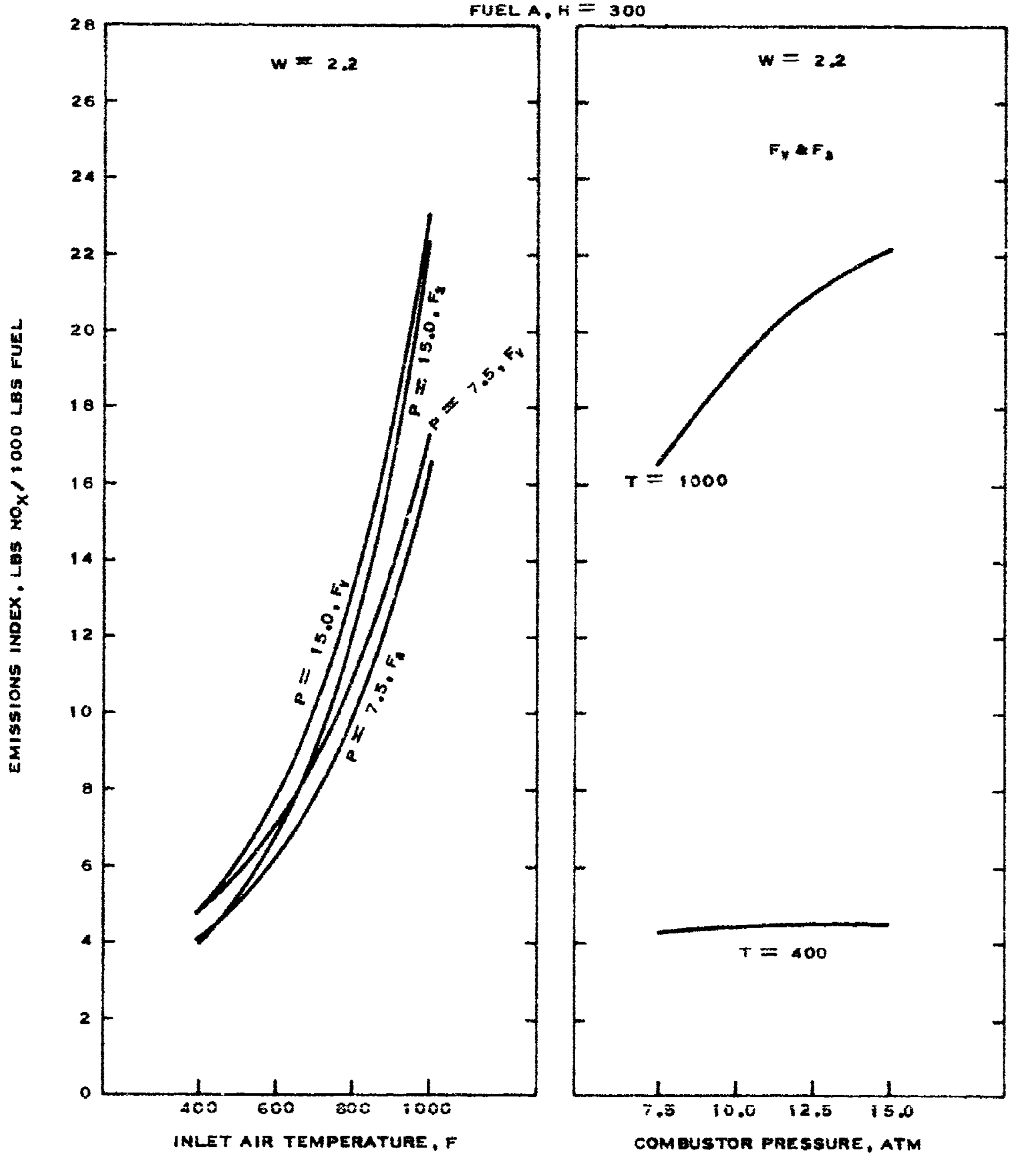

FIGURE 54
CALCULATED NO_x EMISSIONS FOR COMPARISONS
OF EFFECTS OF TEMPERATURE AND PRESSURE

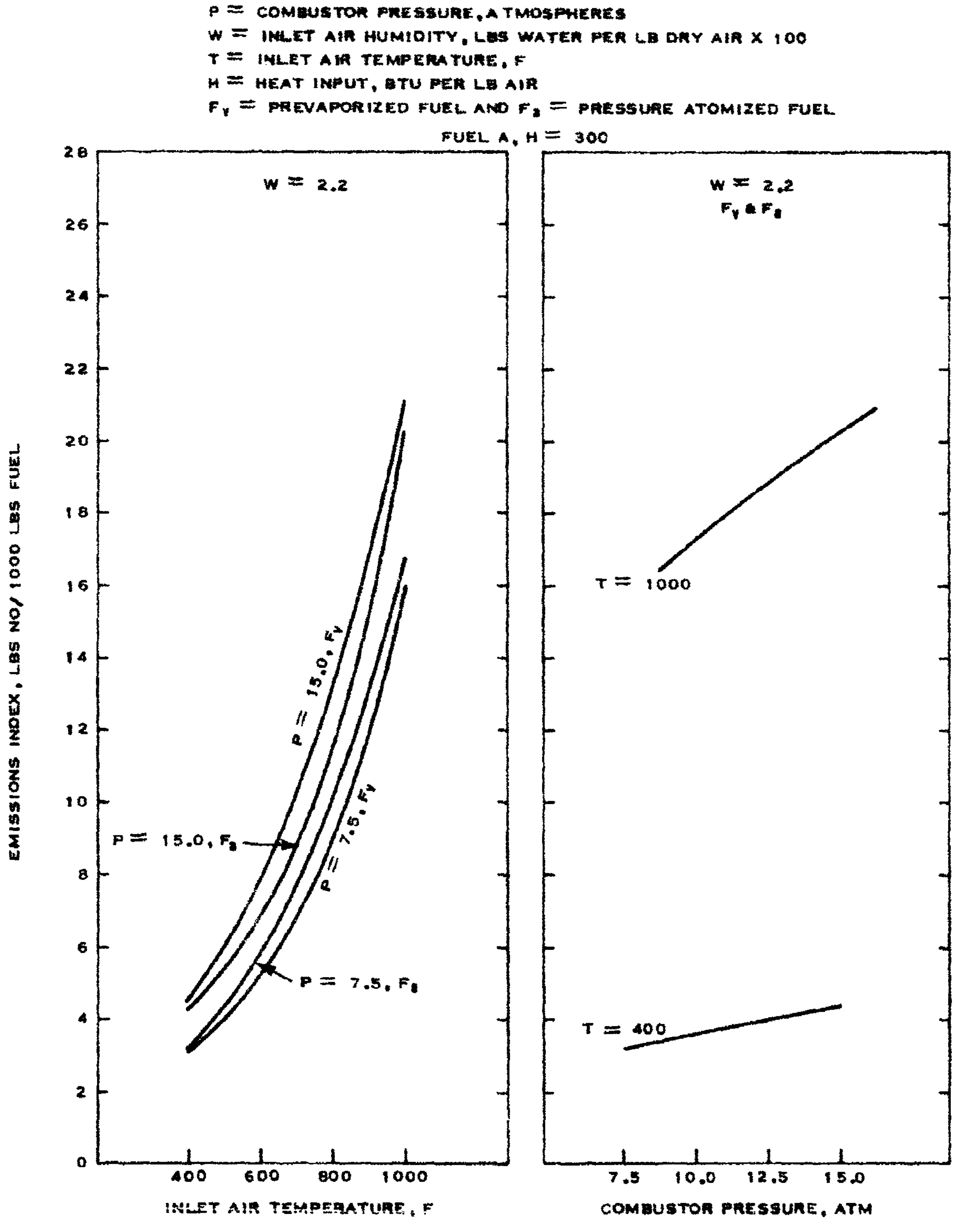

FIGURE 55
CALCULATED NO EMISSIONS FOR COMPARISONS
OF EFFECTS OF TEMPERATURE AND PRESSURE

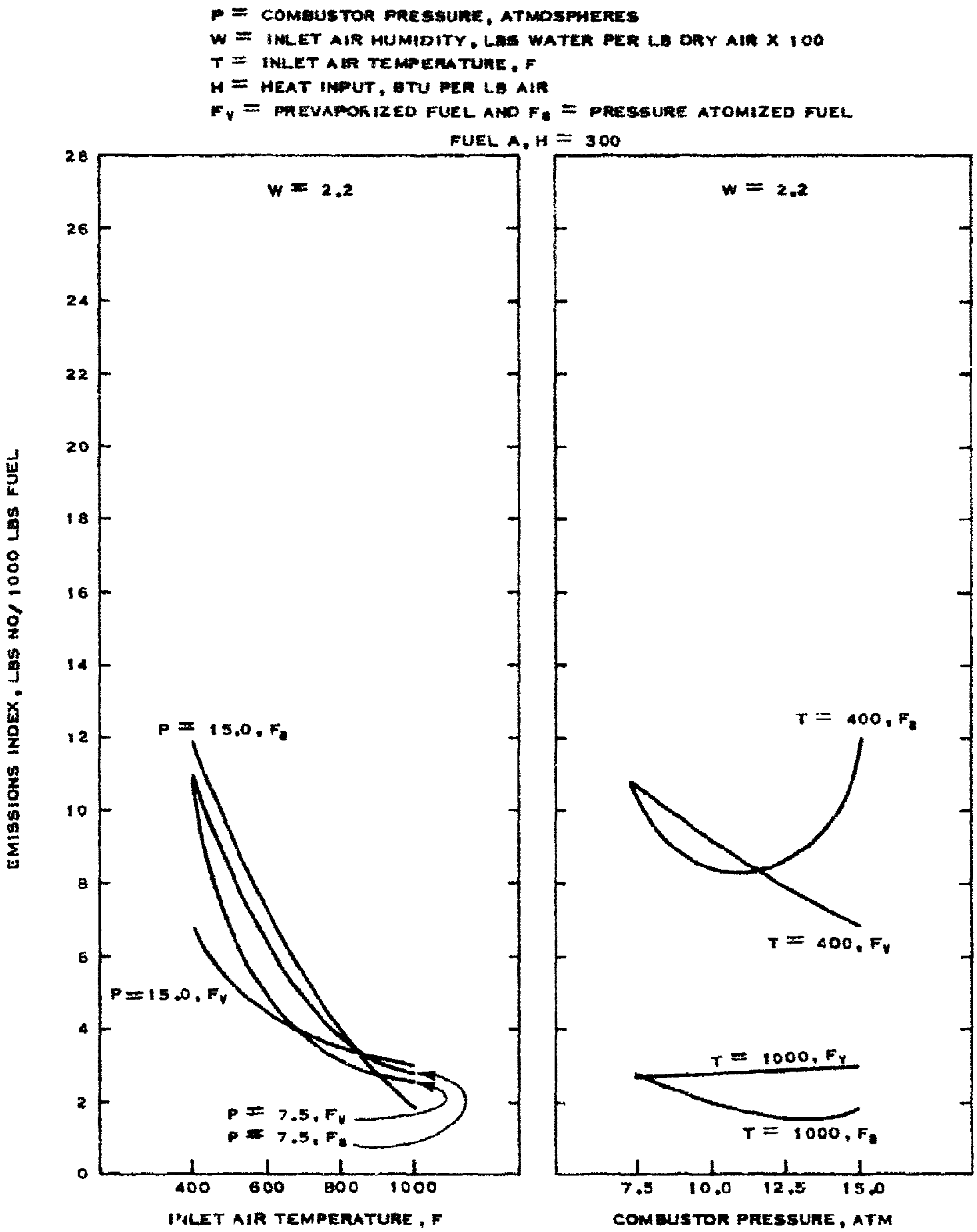

FIGURE 56
CALCULATED CO EMISSIONS FOR COMPARISONS
OF EFFECTS OF TEMPERATURE AND PRESSURE

P = COMBUSTOR PRESSURE, ATMOSPHERES
W = INLET AIR HUMIDITY, LBS WATER PER LB DRY AIR X 100
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_v = PREVAPORIZED FUEL AND F_a = PRESSURE ATOMIZED FUEL

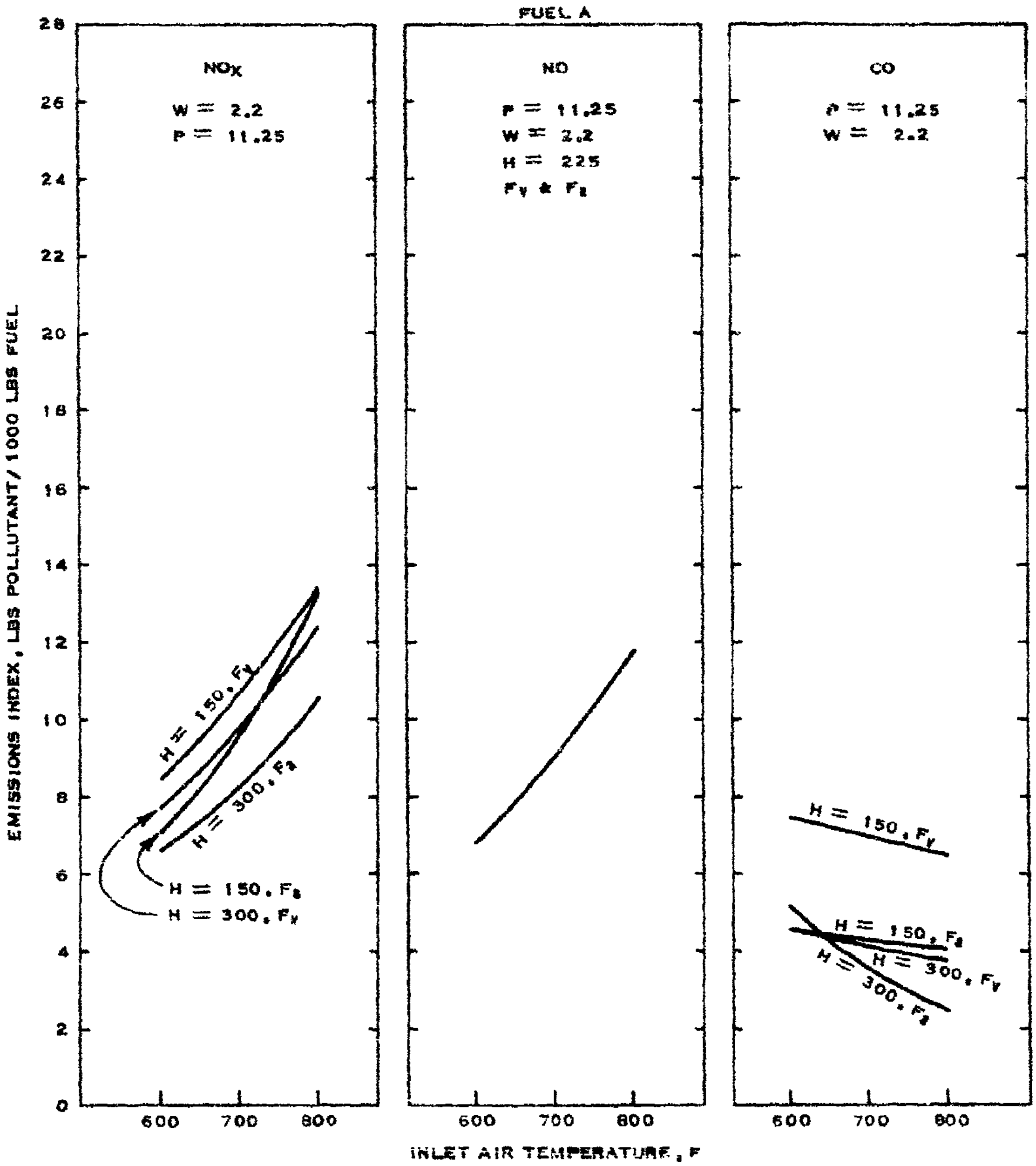

FIGURE 57
CALCULATED EMISSIONS FOR COMPARISONS
OF EFFECTS OF INLET AIR TEMPERATURE

P = COMBUSTOR PRESSURE, ATMOSPHERES
W = INLET AIR HUMIDITY, LBS WATER PER LB DRY AIR X 100
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_v = PREVAPORIZED FUEL AND F_s = PRESSURE ATOMIZED FUEL

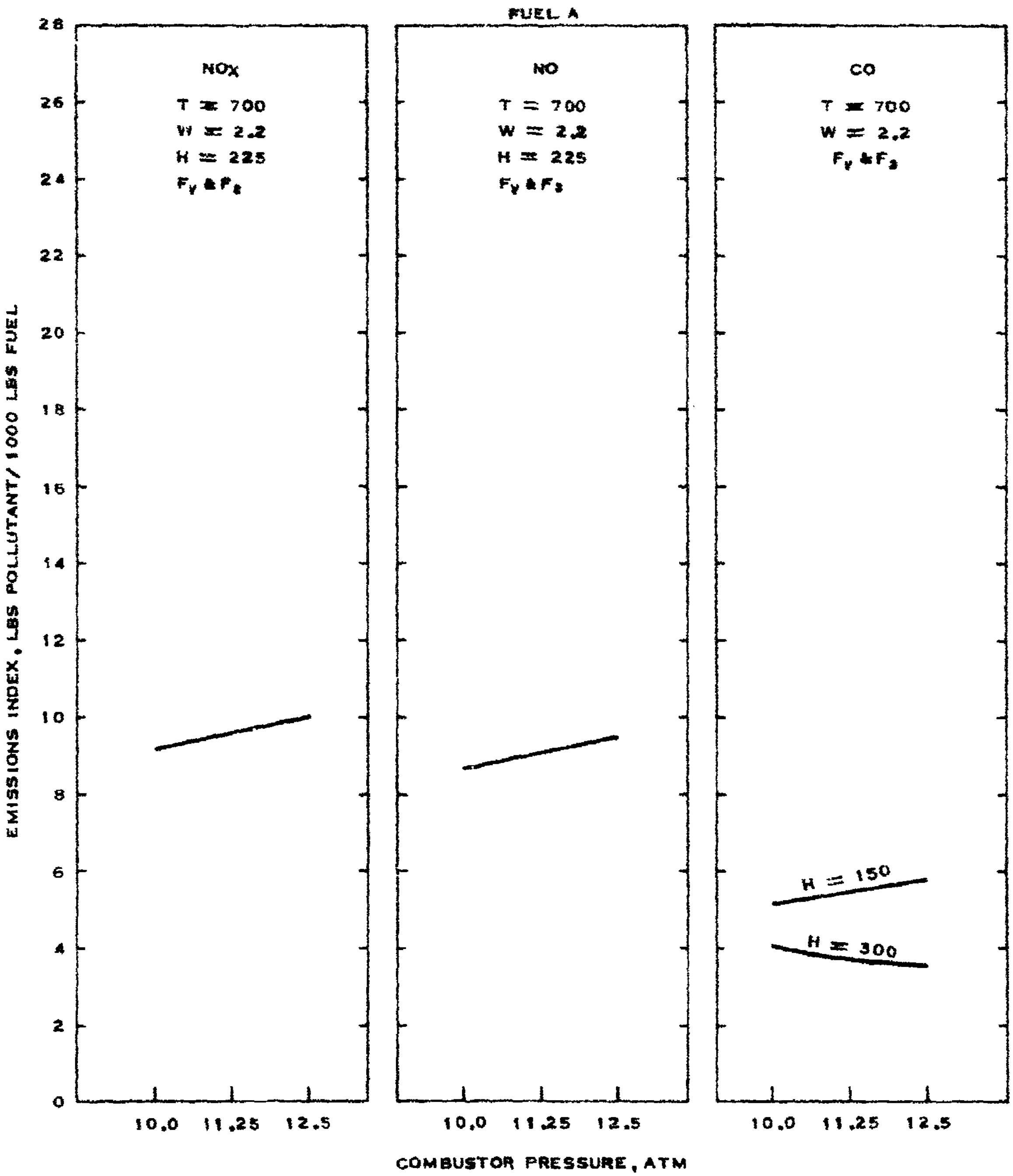

FIGURE 58
CALCULATED EMISSIONS FOR COMPARISONS
OF EFFECTS OF COMBUSTOR PRESSURE

P = COMBUSTOR PRESSURE, ATMOSPHERES
W = INLET AIR HUMIDITY, LBS WATER PER LB DRY AIR X 100
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_V = PREVAPORIZED FUEL AND F_A = PRESSURE ATOMIZED FUEL

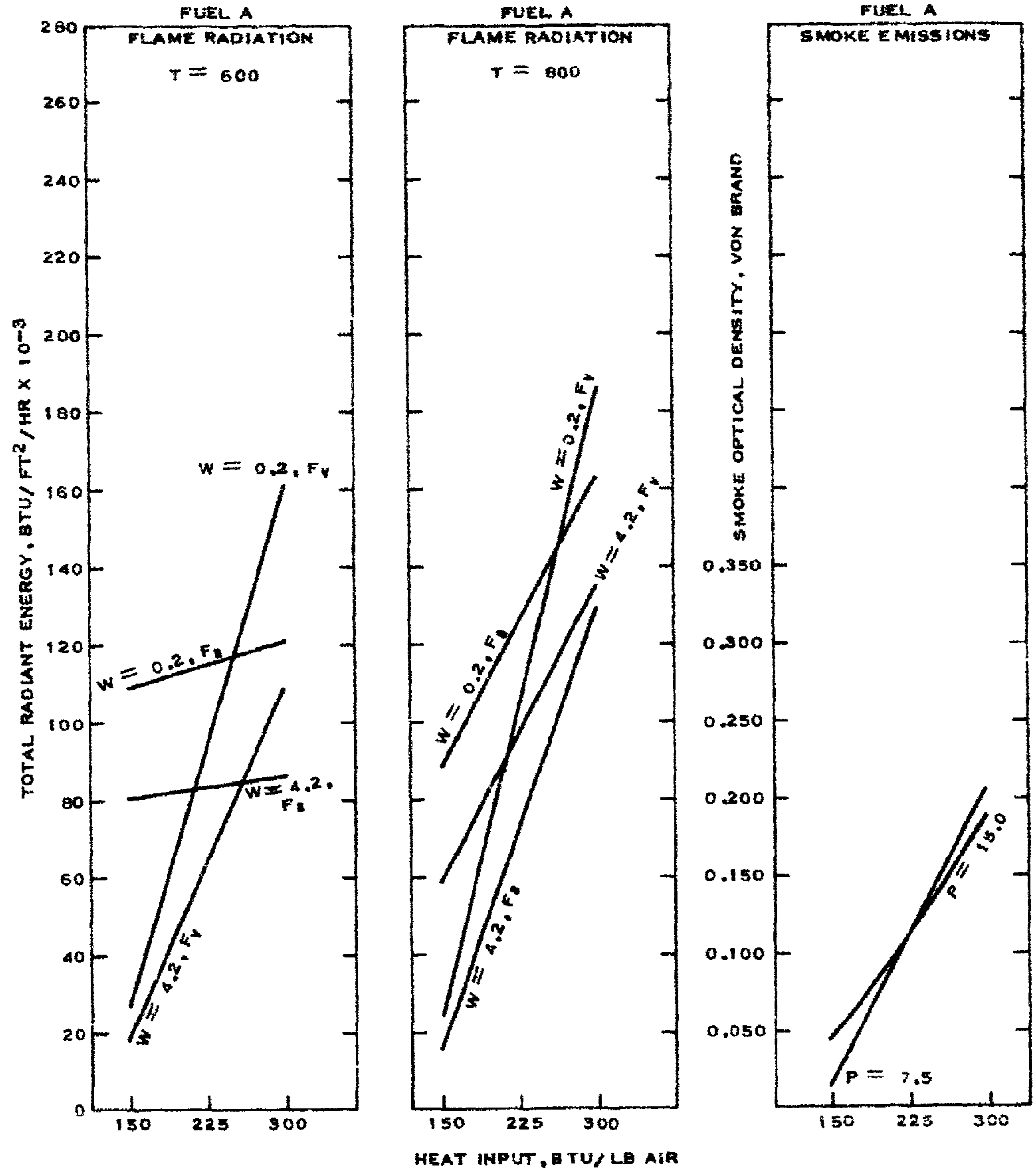

FIGURE 59

CALCULATED EMISSIONS FOR COMPARISONS OF EFFECTS OF HEAT INPUT RATE

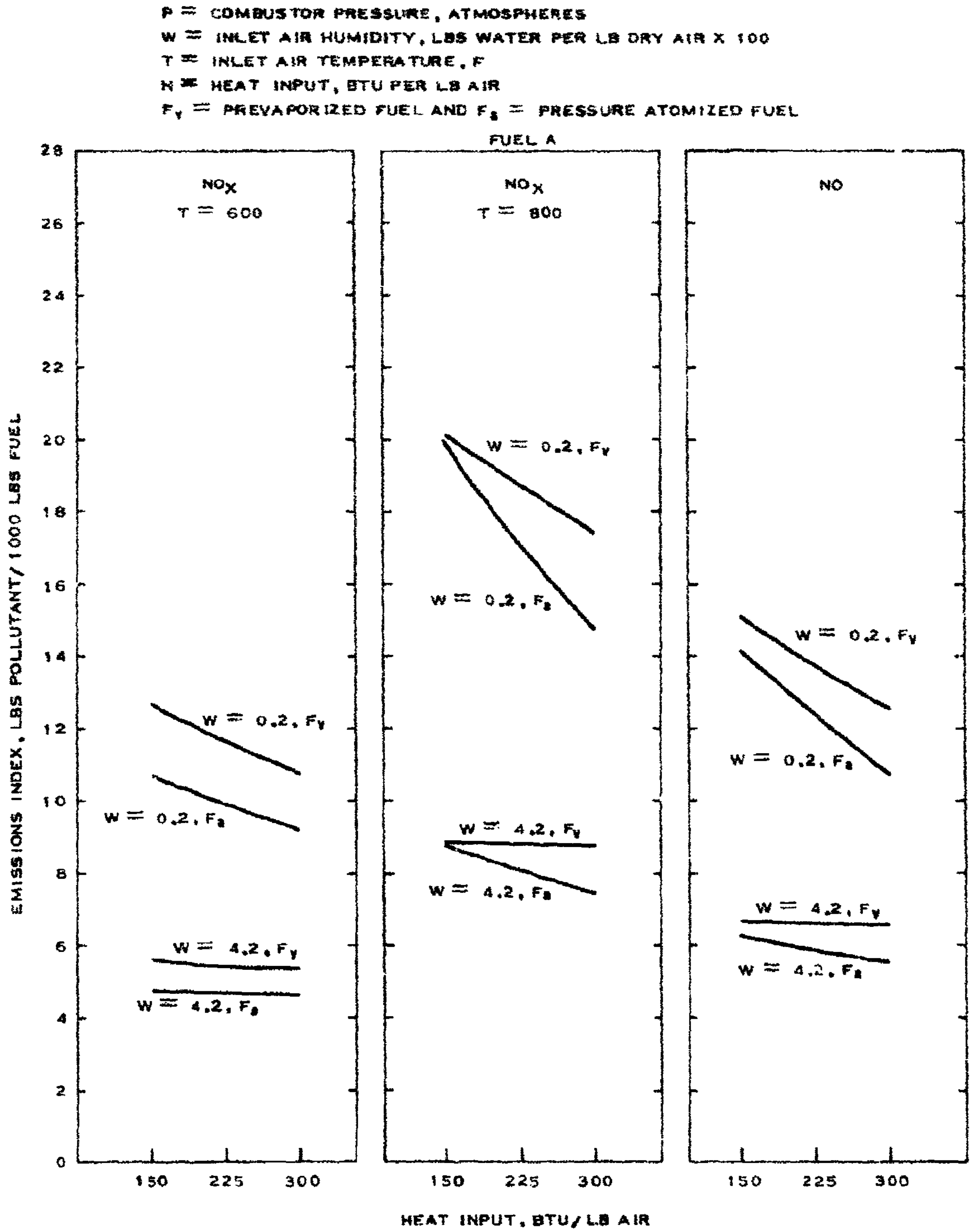

FIGURE 60
CALCULATED EMISSIONS FOR COMPARISONS OF EFFECTS OF HEAT INPUT RATES

P = COMBUSTOR PRESSURE, ATMOSPHERES
W = INLET AIR HUMIDITY, LBS WATER PER LB DRY AIR X 100
T = INLET AIR TEMPERATURE, F
H = HEAT INPUT, BTU PER LB AIR
F_V = PREVAPORIZED FUEL AND F_S = PRESSURE ATOMIZED FUEL

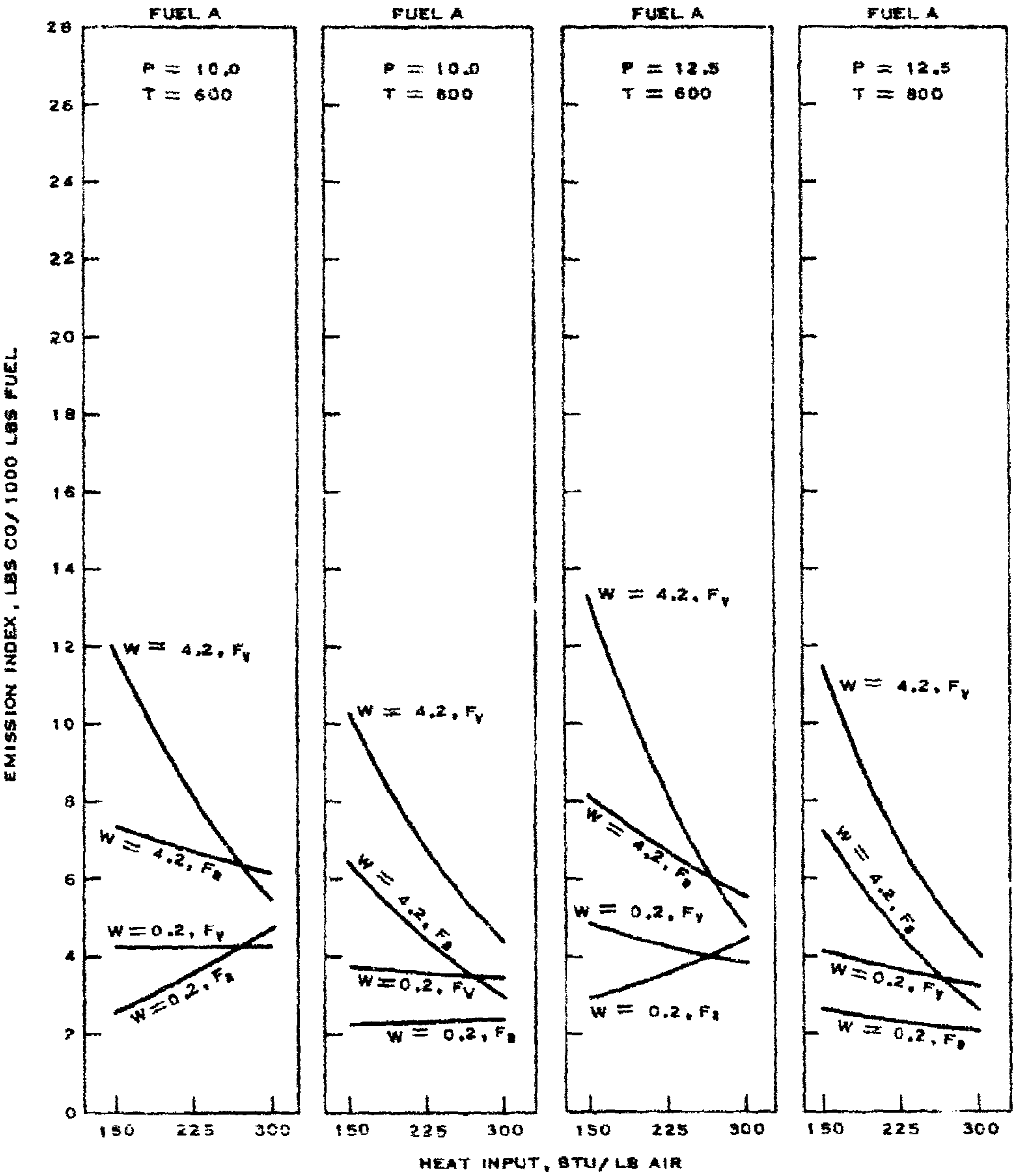

FIGURE 61
CALCULATED CO EMISSIONS FOR COMPARISONS
OF EFFECTS OF HEAT INPUT RATE

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13. ABSTRACT An experimental investigation was conducted, using the Phillips 2-inch combustor operated under conditions simulating those in modern aircraft turbine engines, to determine the effects of differences in JP fuels on flame radiance and exhaust emissions. Kerosene-type fuels spanning the range in molecular structure (normal paraffins, isoparaffins, cycloparaffins, and aromatics) are used in the investigation. Two programs are included to provide a wide range of operating variables for evaluation of the effects of fuels on flame radiance and emissions. One program covers a broad range of combustor pressure, inlet air temperature, inlet air humidity and two methods of introduction of fuel to the combustor (prevaporized and pressure atomized) and is limited to a single level of heat input for five test fuels. The other program covers a range of heat input rates but is limited in range of inlet air temperature and combustor pressure.

Empirical equations are developed for each of five responses for the two programs. Values are calculated for the responses of the estimates equations at the extremes of the ranges of the operating variables used in developing the equations. The data obtained are presented in graphical form and provide visual comparisons of the effects of fuels and operating variables on flame radiance and exhaust emissions of smoke, NO_x, NO, and CO. The measured values of unburned hydrocarbons in this investigation were either zero or very low and detailed analyses of the effects of fuels and operating variables on unburned hydrocarbons is not presented.

Conclusions are presented as to the effects of fuels, prevaporized vs pressure atomized fuel, inlet air humidity, inlet air temperature, combustor pressure and heat input rate on flame radiance and emissions of smoke, NO_x, NO, and CO.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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